An investigation into the integration of qualitative and quantitative techniques for addressing systemic complexity in the context of organisational strategic decision-making

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AN INVESTIGATION INTO THE INTEGRATION OF QUALITATIVE AND QUANTITATIVE TECHNIQUES FOR ADDRESSING SYSTEMIC COMPLEXITY IN THE CONTEXT OF ORGANISATIONAL STRATEGIC DECISION-MAKING

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ABSTRACT

System dynamics modelling has been used for around 40 years to address complex, systemic, dynamic problems, those often described as ‘wicked’. But, system dynamics modelling is not an exact science and arguments about the most suitable techniques to use in which circumstances, continues. The nature of these ‘wicked’ problems is investigated through a series of case studies where poor situational awareness among stakeholders was identified. This was found to be an underlying cause for management failure, suggesting need for better ways of recognising and managing ‘wicked’ problem situations. Human cognition is considered both as a limitation and enabler to decision-making in ‘wicked’ problem environments. Naturalistic and deliberate decision-making are reviewed. The thesis identifies the need for integration of qualitative and quantitative techniques. Case study results and a review of the literature led to identification of a set of principles of method to be applied in an integrated framework, the aim being to develop an improved way of addressing ‘wicked’ problems. These principles were applied to a series of cases in an action research setting. However, organisational and political barriers were encountered. This limited the exploitation and investigation of cases to varying degrees.

In response to a need identified in the literature review and the case studies, a tool is designed to facilitate analysis of multi-factorial, non-linear causality. This unique tool and its use to assist in problem conceptualisation, and as an aid to testing alternate strategies, are demonstrated. Further investigation is needed in relation to the veracity of combining causal influences using this tool and system dynamics, broadly. System dynamics modelling was found to have utility needed to support analysis of ‘wicked’ problems. However, failure in a particular modelling project occurred when it was found necessary to rely on human judgement in estimating values to be input into the models. This was found to be problematic and unacceptably risky for sponsors of the modelling effort. Finally, this work has also identified that further study is required into: the use of human judgement in decision-making and the validity of system dynamics models that rely on the quantification of human judgement.

PREFACE

This dissertation has a broader agenda than integrating various system dynamics modelling techniques. It seeks *to determine how to support decision-makers and strategy developers through decisions in complex real-life settings*. In particular, it aims to establish the comparative effectiveness of qualitative and quantitative system dynamics modelling as an enabling step to determining when to use qualitative and when to use quantitative methods. It does this by firstly considering how managers make decisions, and by looking at a number of real world settings. The success and failure of decision-making and strategy development are examined to establish why failure occurs and when success occurs. This information is used to develop a set of theoretical and practical principles of method. Limitations to the practical applications are examined through a number of real-world cases. The extent of success achieved is then reviewed.

Scope of this research is:

a. Chapter 1 recognises that the notion of an *Entire Invariant Paradigm* is severely limiting in a complex world. Once we recognise this and the complexity of the world around us, we should readily accept our human cognitive limitations in dealing with that complexity, especially when dynamic situations are involved. Further, there can be many stakeholders and many factors interacting in ways that make management of complexity very difficult.

b. In Chapter 2, the ways decision-makers think, choose and act are analysed as part of a literature review. The intent is to set the scene for later chapters leading to the development of principles of method for addressing complex, dynamic, systemic problems.

c. Through Chapters 3 and 4, a number of well-documented real-life cases are studied in detail. Innovative and extensive use of concept mapping uncovers the true nature of detail and dynamic complexity faced, knowingly or unwittingly, by managers, executive decision-makers and strategy developers. Noting that most complex, dynamic, systemic problems do not result in tragedy, as occurred in the cases described at Chapters 3 and 4, the analysis reveals that evolving problems frequently went unnoticed, or continued to evolve without effective remedy. So the intent of this thesis is refined; to find ways to assist managers, executive decision-makers, strategy developers, researchers and practitioners working in the field, to recognise problems before they develop to the point where undesirable or tragic outcomes are likely.

d. In Chapter 5, observations from concept mapping of real-life cases provide the basis for characterisation of 'wicked' problems. This work expands on a previous characterisation set that required updating on the basis of observations from Chapters 3 and 4 and recent literature. The result is an essential and novel definition of the basis for the application of ways of thinking about and analysing complex, dynamic and systemic 'wicked' problems.

e. Chapter 6 combines the principles of method developed from the work in earlier chapters with observations from the literature to describe a new framework for addressing 'wicked' problems. Whilst a number of frameworks can be found in the literature, this one is new insofar that it is specifically built on knowledge derived from detailed, empirical analysis and characterisation of 'wicked' problems. It is also built on knowledge of the limitations of traditional methods. Lessons from recent research into choice and decision-making are combined with observations made in the system dynamics literature regarding human cognitive limitations in dealing with complexity.

f. In Chapter 7, application of the principles of method and the new framework is demonstrated through the medium of a tutorial.

g. Chapters 8-10 describe the application of the principles of method to a series of cases. This work is done through action research. Lessons taken from this work are combined to strengthen the principles of method and framework described at Chapter 7. The need for a conceptualisation support and causal analysis tool, a System Dynamics 'Front End' Tool was identified in the literature. The need is reinforced by observations from early case studies. The need for this tool is further reinforced by observations made during the case application work.

h. To fulfil the need for enhanced conceptualisation support and causal analysis, and to provide much needed rigour, a unique System Dynamics 'Front End'

Tool is developed and demonstrated. This is described at Chapter 11. The tool exploits additive fuzzy arithmetic. Threats such as double counting of causal influences, as might arise in causal loop diagramming, are identified and overcome. This tool also facilitates limited dynamic analysis. Outcomes might include rapid development of outline strategies for addressing quite complex problems, or to inform the choice to proceed to development of quantitative system dynamics modelling. This tool fills a gap between qualitative and quantitative system dynamics identified both in the literature and cases studied at Chapters 3 and 4.

i. Chapter 12 reviews the research effort with particular focus on the outcomes of the case applications. Analysis of Strengths / Weaknesses / Opportunities and Threats (SWOT) is used to critically examine the achievements. In closing is a summary of the need for future work.

Significant contributions made to the extant body of knowledge are:

a. Review of managerial cognition and decision-making as the basis for formulating decision-support systems built around systems thinking and system dynamics (Chapter 2). Whilst not new to the field of cognitive psychology this review is considered to be an essential baseline for subsequent analysis. Treatment as complete as this, has been absent from the system dynamics literature.

b. Through case study analysis, produced a set of observations about the nature of wicked problems, and organisational dealings with those problems (Chapters 3 and 4). These observations suggest reasons why decision-making and strategy development fail.

c. Based on analysis of real-world cases, an existing characterisation of wicked problems was expanded. This became the foundation upon which to design decision-support systems for addressing wicked problems (Chapter 5).

d. Based on case studies, literature review and characterisation of wicked problems, developed a problem solving framework built around the set of principles of method developed (Chapter 6), and demonstrated application of these principles through a detailed tutorial (Chapter 7) representing system dynamics ‘best practice’.

e. Identified strengths, weaknesses, opportunities and threats to application of principles of method and ‘best practice’ in system dynamics in an organisational context (Chapters 8, 9, and 10).

f. Demonstrated the prototype design of a unique tool and associated set of techniques for first pass analysis of wicked problems, which builds rigour into causal loop diagramming (Chapter 11).

g. Identified and suggested refinements to system dynamics ‘best practice’ and its application (Chapter 12).

Use of Action Research Approach

The work described in this dissertation was undertaken using an action research approach. Such work is very different to ‘laboratory’ experimentation. Action research frequently changes its direction. The sequence of presentation in the chapters is not the sequence in which the work was done. To present the dissertation in the circuitous sequence of conduct of the work would be confusing to the reader. To aid the reader, the following guides have been included:

a. <u>Reader’s Roadmap</u>. It is suggested this roadmap, Figure P-1, be read in conjunction with the synopses and summaries of each chapter.

b. <u>Action Research Sequence</u>. Figure P-2 outlines the chronological sequence of development of the action research activities.

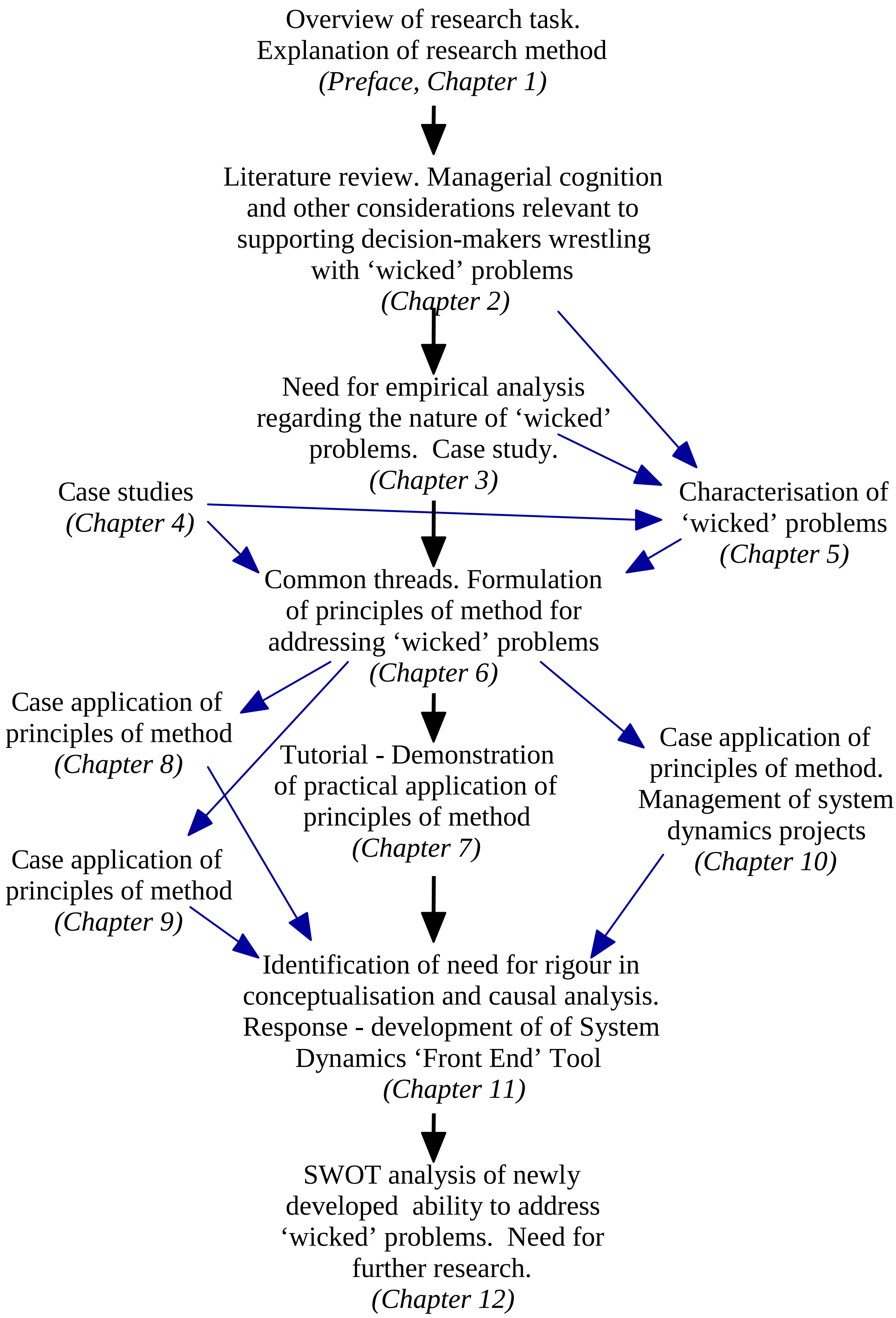

Figure P-1 Reader's Roadmap (1)

<u>Note</u>:

1. It is recommended that chapters linked by bold arrows be read first. Remaining chapters may be read on an 'as required' basis.

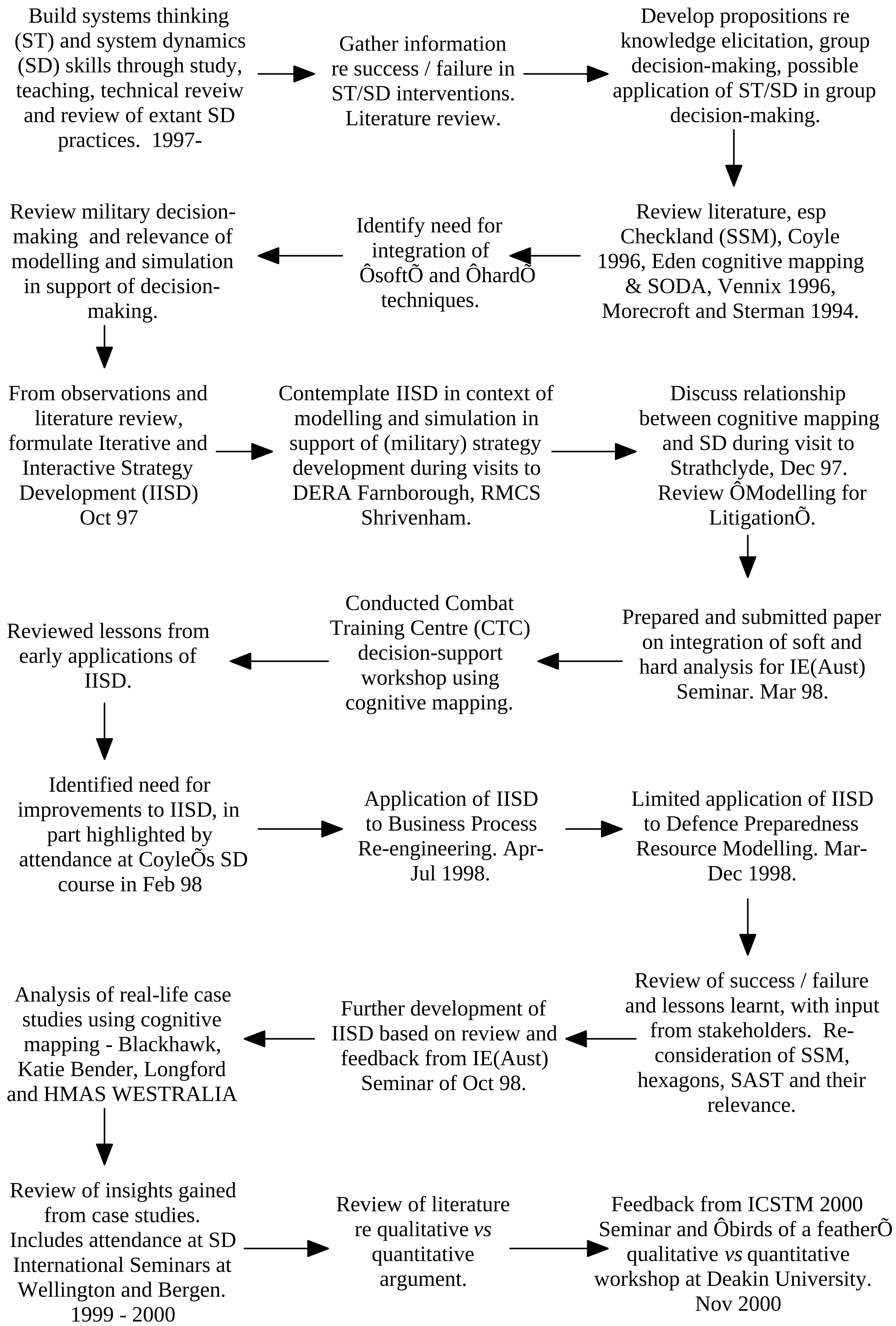

Figure P-2 Action Research Sequence

PUBLICATIONS

Journal Publications

The following have been published in the course of the work associated with this thesis.

McLucas, A.C. 1999. 'Systems thinking and system dynamics modelling – aids to decision making: A case study in reliability prediction.' In: *Journal of Battlefield Technology,* Vol. 2, No. 2, July 1999.

McLucas, A.C. 2000. 'Rectifying the failure to learn in complex environments.' In: *Journal of Battlefield Technology*, Vol. 3, No. 3, November 2000: 42- 50.

Refereed Seminar Papers

McLucas, A.C. 1998. 'Integrating soft and hard systems analysis: Seeking a practical framework for addressing strategic problems.' In: *Proceedings of SE'98: Systems engineering pragmatic solutions to today's real world problems,* Systems Engineering Society of Australia, Oct 1998.

Linard, K. and McLucas A.C. 1999. 'Addressing complexity and systemic behaviour in engineering management: A tutorial for real-life problems.' In: *UICEE Proceedings of the 2nd Asia-Pacific Forum on Engineering & Technology Education*, July 1999. *Lead Paper*.

McLucas, A.C. 2000. 'When to use qualitative or quantitative system dynamics techniques: guidelines derived from analysis of recent man-made catastrophes.' In: *Proceedings of System Dynamics 2000, International System Dynamics Conference,* The System Dynamics Society, Bergen, Norway, August 2000.

McLucas, A.C. and Linard K.T. 2000. 'System dynamics practice in a non-ideal world: modelling Defence prepareness.' In: *Proceedings of System Dynamics 2000, International System Dynamics Conference*, The System Dynamics Society, Bergen, Norway. *Plenary Paper*.

McLucas, A.C. 2000. 'To model or not to model.' In: *Proceedings of International Conference of Systems Thinking in Management Conference,* Deakin University, Australia, Nov 2000.

McLucas, A.C. 2000. ‘The worst failure – repeated failure to learn.’ In: *Proceedings of International Conference of Systems Thinking in Management Conference,* Deakin University, Australia, Nov 2000.

A copy of McLucas (1999) is enclosed at Annex D.

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ABBREVIATIONS

A21	Australian Army in the 21st Century
AAAvn	Australian Army Aviation
ABC	Applied Behavioural Cognition (Research Group)
ACT	Australian Capital Territory
ADO	Australian Defence Organisation
ADF	Australian Defence Force
ADFA	Australian Defence Force Academy
AEC	Air Element Commander
AIDA	Analysis of Interconnected Decision Areas
AIT	Army Air Accident Investigation Team
AMS	Acquisition Management Systems
ANAO	Australian National Audit Office
AS/NZS	Australian / New Zealand Standard
Avn	Aviation
BOI	Board of Inquiry
BPR	Business Process Re-engineering
C	Complexity Index
C2	Command and Control
CA	Chief of Army
CAPT	Captain
CBD	Central Business District
CDF	Chief of Defence Force
CD-ROM	Compact Disc – Read Only Memory
CEP	Capital Equipment Procurement
CEPMAN	Capital Equipment Procurement Manual
CPS	Creative Problem Solving
CS^2	Cost Schedule Control Systems
CSSR	Cost Schedule Status Reporting
CT	Counter Terrorist
CTC	Combat Training Centre

CV	Cost Variance
DAO	Defence Acquisition Organisation
DER	Defence Efficiency Review
DGAMS	Director General Acquisition Management Systems
DMO	Defence Materiel Organisation
DOA87	1987 White Paper *Defence of Australia*
DoD	Department of Defence
DMO	Defence Materiel Organisation
DPRM	Defence Resource Preparedness Modelling
DRP	Defence Reform Programme
FE	Force Element
FEG	Force Element Group
FSB	Fire Support Base
FSPPC	Force Structure Planning and Programming Committee
GMB	Group Model Building
GSO	General Service Officer
GUI	Graphical User Interface
HBIS	Head Business Information Systems
HDL	High Density Lipids
HMAS	Her Majesty's Australian Ship
HQ	Headquarters
ICSTM	International Conference on Systems Thinking in Management
IISD	Iterative and Interactive Strategy Development
ILS	Integrated Logistic Support
JOURNEY	JOint Understanding, Reflecting and NEgotiating strategY
KPI	Key Performance Indicator
L	The number of control *feedback Loops* both within the system under study and connection the system to the surroundings
LDL	Low Density Lipids
LTGEN	Lieutenant General
MAJ	Major
MAJGEN	Major General
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration
NVG	Night Vision Goggles

OC	Officer Commanding
OMT	Oval Mapping Technique
OODA	Observe, Orient, Decide, Act
OPSO	Operations Officer
OR	Operations Research
P	The number of independent *Parameters* needed to distinguish the system under study from other systems in the same class
PMI	Project Management Institute
PRINCE	PRojects IN Controlled Environments
ProMIS	Project Management Information Systems
PR&E	Performance Reporting and Evaluation
QFI	Qualified Flying Instructor
RAAF	Royal Australian Air Force
Regt	Regiment
RGA	R.G. Glenn and Associates
RTA	Restructuring the Australian Army
SASR	Special Air Service Regiment
SAST	Strategic Assumptions Surfacing and Testing
SCA	Support Command – Army
SCS	Soldier Combat Systems
SD	System Dynamics
Sim	Simulation
SO1	Staff Officer Grade One
SODA	Strategic Options Development and Analysis
SOP	Standing Operating Procedures
Sqn	Squadron
SRO	Special Recovery Operations
SSO	Specialist Service Officer
SSM	Soft Systems Methodology
SV	Schedule Variance
T	Temporal
UH	Utility Helicopter
USA	United States of America
V	The number of independent *Variables* needed to describe the state of the system under study.

VCDF	Vice Chief of the (Australian) Defence Force
WBS	Work Breakdown Structure

GLOSSARY

Autonomic. Designates a kind of feedback control that is built-in and rigid in a sense that it does the same thing every time (Kline, 1995: 315). Also see *cybernetic*, *feedback*.

Bounded rationality. Criticism of classical rationality led Nobel laureate Herbert Simon (1972) to propose the notion of *bounded rationality*. Bounded rationality is based on behavioural notions and upon observations of the ways in which decisions are actually taken in practice. It assumes human rationality has its limits, especially when operating in conditions of considerable uncertainty. Bounded rationality has two interlocking components:

Limitations of the human mind. Models of human judgement and decision making have to take into account known limitations about the mind's capacities. Because of the mind's limitations, humans "must use approximate methods to handle most tasks" (Simon, 1990: 6). These methods include recognition processes that largely obviate the need for further information search, heuristics (mental shortcuts) that guide search and determine when it should end, and simple decision rules that make use of the information found.

Structure within which the mind operates. Environmental structure is of crucial importance because it can explain when and why simple heuristics perform well: if the structure of the heuristic is adapted to that environment. A heuristic is said to be *ecologically rational* to the degree that it is adapted to the structure of an environment.

For further explanations of bounded rationality terms, those in italics, see Gigerenzer et al., 1999. Also see *satisficing*, below.

Call for action. *Cognitive maps*, *concept maps*, cause maps and diagrammatic representations of strategy are normally and deliberately coded with an active verb so that each of the ideas, notions, personal constructs or concepts contained in them constitutes a *call for action*. This is both an aid to minimising ambiguity and to guide the process of 'manage and control' which is meant to flow through pairs of linked concepts. A *call for action* at the tail (source) of a causal link is intended to result in some form of management or control action at the head (sink) of that link. For a more detailed explanation of *call for action,* see Eden and Ackermann (1998a: 94, 160, and 290).

CATWOE. A mnemonic of the six crucial characteristics which should be included in a well formulated *root definition*:

C*ustomer* – beneficiary or victim of the system's activity.

A*ctor* – a person who carries out one or more of the activities in the system.

T*ransformation Process* – the core transformation process of a *human activity system* is expressed as the conversion of some input to some output.

W*eltanschauung* – the (unquestioned) image or model of the world which makes this particular *human activity system* (with its particular transformation process) a meaningful one to consider.

O*wner* – the person or persons who could modify or demolish the system.

E*nvironmental Constraints* – impositions which the system takes as given (Checkland, 1993: 312-319).

Causal loop diagram. A *causal loop diagram* is a convenient way of representing the principal feedback loops and related causal relationships relevant to a particular problem situation, without distinguishing between the nature of the interconnected variables. In the first instance causal loop diagrams serve as preliminary sketches of causal hypotheses. Later, they enable the essential components and interrelationships to be summarised. Arrows are used to indicate direction of causal influences. Signs (+ or -) adjacent the arrows indicate *polarity,* that is, how a change in the variable at the tail of the arrow will produce a change at the head of the arrow. Fundamentals of causal loop diagrams are described by Goodman (1989). For a detailed explanation of causal loop diagrams, see Sterman (2000: 137-190). For an exposé of the problems in the use of causal loop diagrams, see Richardson, 1986.

Causality (cognitive or concept map). *Causality* or *causal relationships* are represented by arrows in cognitive or concept maps, where each arrow means 'leads to… ', such as is expressed in the statement 'smoking *leads to* heart disease. This does not mean all smokers will suffer from heart disease but suggests there is strong evidence to this effect, noting all people who smoke will be affected, at least to some extent.

Causality (causal loop diagram. In a *causal loop diagram*, the influence of one variable on another is *causality* (Richardson, 1986; Sterman, 2000: 137-190).

Causal Link. A *causal link* in a causal loop diagram, cognitive map, concept map, influence diagram depicting causality.

Choke point. A *choke point* is a *leverage point* that can work against us. By noticing choke points we buy ourselves time to take preventative action before an emergency arises, or undesirable consequences manifest themselves. Also see *leverage point*.

Conflicting Link (cognitive or concept map). *Conflict relationships* are a special case of the *connotative relationship*, but where the concepts at the ends of each line cannot co-exist without conflict, or a state of stress being created. A couple of different conventions are used to denote conflict, either a red line is used or the link is marked 'CONFLICT'. Both conventions have the same meaning.

Cognition. *Cognition* is the faculty of knowing, perceiving and conceiving (conceptualising). In the context of this work, cognition is a capacity that emerges along with consciousness as the awareness of strategic choice. This consciousness occurs at the implicit level, where judgement is being exercised, just as it does at the higher levels where deliberate and conscious choices are made. The key to cognition lies in the development of consciousness (Eden and Spender, 1998: 34) or *situational awareness* (Klein, 1998). Also see *situation awareness*.

Cognitive Map. A *cognitive map* is a personal mind map or a mapping of the thoughts an individual has about a particular situation or problem of interest. The form of cognitive mapping used in this thesis follows that of Eden et al., (1979), which is an exploitation of George Kelly's (1956) *Psychology of Personal Constructs*.

Concept. In general usage, a *concept* is a general notion. In *concept mapping*, a *concept* is also an idea or general notion. *Concepts* range from hard, physical ideas, or notions, to *fuzzy* ideas which involve or describe entities without measurable units. Just as in *cognitive mapping* where individual concepts are expressed as a *call for action*, in *concept mapping* the same conventions are followed. Also see *concept mapping* and *fuzzy logic*.

Concept Map. A *concept map* is a mind map, which contains the perspectives and inputs of several individuals. Strictly speaking, a *concept map* is not a *cognitive map* because cognition belongs to individuals, not to groups of individuals, or organisations. See Eden and Ackermann, 1998b: 192-209.

Connotative Link. Links where causality may act in either direction at different times or under varying circumstances. This type of link suggests causality is ill-defined, open to interpretation, or requiring further observation and investigation. *Connotative links* are often use to connect concepts having a system policy input. Varying such a concept may have significant impact on connected concepts. Connotative relationships are depicted by lines without arrowheads. To start, we will use dotted lines to depict connotation.

Complexity. *Complexity* describes that which comprises myriad parts, or which is complicated in nature. Complexity can be considered a comprising two forms, *detail* and *dynamic*. *Detail complexity* describes too many factors to be considered at any one time. *Dynamic complexity* describes behaviour we observe which changes over time, where the patterns of change are familiar but the underlying factors that produce change over time may be obscured. Fundamentally, a system is complex when we cannot understand it through simple cause-and-effect relationships or other standard methods of systems analysis. In a complex system, we cannot reduce the interplay of individual elements to the study of individual elements considered in isolation. Often, several different models, each at a different level of abstraction, are needed. Also see *complexity theory*.

Complexity Index. The *Complexity Index, C,* is used to indicate inherent complexity of a problem, or class of problems. *C* is defined in terms of:

V = The number of independent *Variables* needed to describe the state of the system.

P = The number of independent *Parameters* needed to distinguish the system from other systems in the same class.

L = The number of control *feedback Loops* both within the system and connecting the system to the surroundings.

The upper and lower values of *C* are defined as

$$V + P + L < C < V \, . \, P \, . \, L,$$

noting that when L = 0, or V and P both have low values, *C* is taken to be V + P + L. For a particular system, the location of the value of *C* between these upper and lower bounds will depend on the degree of 'connectedness' within the structure of the system and between the system and its surroundings (Kline, 1995: 49-51).

Complexity Theory. Complexity theory begins by acknowledging the interrelated nature of things as well as *emergence*, where the whole is experienced as greater than the sum of the parts. It recognises a special form or emergence called spontaneous self-organisation. What exactly gives rise to spontaneous self-organisation is difficult if not impossible to know, at least by the human mind. Complexity theory appreciates the world as a whole, comprising many, man interrelationships expressed as endless occurrences of spontaneous self-organisation. The great extent and dynamic nature of the interrelationships and spontaneous self-organisation means that is it is only possible for us to get to grips with some things and only those that are local to us in space and time (Flood, 1999: 2). Complexity theory (Kaufman, 1995; Axelrod, 1997; Holland 1998) as an emerging field of study has evolved from five major knowledge areas: mathematics, physics, biology, organisational science, and computational intelligence and engineering.

Cybernetic. Norbert Wiener's work for autonomic feedback control (Kline, 1995: 315; Wiener, 1948). Also see *autonomic, feedback.*

Damping. Vibration, or free oscillations, of real world systems do not persist indefinitely, that is, they die out gradually unless excited by some external agent or force. Without external excitation, oscillations are suppressed or *damped* by resistances to the motion. All real world systems contain inherent *damping*. In physical systems damping is produced by friction or internal energy losses. Frequently, damping is intentionally imposed as a controlling mechanism.

Decision (decision event). A *decision* is made, or a *decision* event occurs, when the decision-maker (generally a single individual) surveys a known and fixed set of alternatives, weighs the likely consequences of choosing each, and makes a choice.

[In an ideal situation], the decision maker evaluates the options in terms of a set of goals, purposes, or values that are stable over time, and that he or she knows quite clearly (Klein, Orasanu, Calderwook and Zsambok, 1993: 5).

Decision event model of decision-making. The *decision event* model of decision-making emphasises concurrent evaluation of multiple options; relies on analytical methods for integrating values and probabilities associated with each option; and seeks an optimal solution (Klein et al, 1993: 6). Also see *naturalistic decision-making*.

Deliverable products. Those entities completed for delivery to the client at a point in time. For example, a model building workshop might produce the following *deliverable products*:

Concept maps of key stakeholders or of the group.

Causal maps or influence diagrams of the system feedback structure.

An operating model.

A list of policy-oriented action steps for the group to carry forward.

An organisational strategy for immediate implementation.

Andersen and Richardson suggest that the most likely outcome at the end of a two-day workshop is a set of model-based insights and action steps. (Andersen and Richardson, 1997: 110). To build a detailed organisational strategy ready for implementation is likely to require several modelling workshops, perhaps supported through intermediate stages by knowledge elicitation activities, employing questionnaires or workbooks. (Vennix, 1996: 128).

Delay. A situation in which an influence from a variable *A* to another variable *B* does not take effect immediately (Powersim Handbook).

Double loop learning. *Double loop learning* occurs when mismatches or errors [difference, δ, between actual and desired states] are corrected by first examining and altering the governing variables and then taking action. Governing variables are the preferred states that individuals strive to "*satisfice*" when they are acting. These governing variables are not the underlying beliefs or values people espouse. They are the variables that can be inferred, by observing the actions of individuals acting as agents for the organisation, to drive and guide their actions.

DT. Delta time, a certain addition or increment to time (Powersim Handbook). System dynamics models are based on integration over time. *DT* is the finite time interval used in such numerical integration.

Emergence (emergent properties). *Emergent properties* are properties exhibited by a complete (hooked-up) system that cannot be exhibited by the parts of the system in isolation (Kline 1995: 316). They depend on interactions between components (including the environment). Consider a bicycle composed of a frame, two wheels, pedals, a drive chain, saddle, handlebars, brakes etc. The primary emergent property of dynamic balance is only produced by the combination of the rider and the bicycle. Only when human power, control and intelligence (and a road surface) are added does the bicycle become a means of transport. Take any one away and the system falls apart. Emergent properties therefore cannot be predicted solely by looking at the components. See Flood (1999), Kline (1995), Senge (1990); and Stevens, Brook, Jackson and Arnold (1998).

Entire invariant paradigm. A principle that not only holds for all known examples in a class of systems but also occurs with the same details in every case. (Kline, 1995: 316).

Epistemology. A theory concerning means by which we may have and express knowledge of the world (Checkland, 1993: 314).

Facilitator / Elicitor. Functioning as group *facilitator* and knowledge *elicitor*, this person pays constant attention to group process, the roles of individuals in the group, and the business of drawing out knowledge and insights from the group. This role is the most visible of the five roles in the group modelling support team, as the facilitator constantly works with the group to further the model-building effort (Richardson and Andersen (1995: 113-137). Also see *process coach, recorder, modelling gatekeeper, modeller / reflector*.

Feedback. *Feedback* occurs when part or all of the output of a system re-enters as the input. Feedback is also used to describe the return of information to influence the next stage in the system. For detailed treatment of feedback and its implications for social science and systems theory, see Richardson (1991).

Feedback. Delivery of reassurance or corrective information upon which learning is based (Forsyth).

Flow. See *rate*.

Fuzzy Logic. *Fuzzy logic* is a superset of conventional (Boolean) logic that has been extended to multi-valued sets, to handle the concept of partial truth, that is, truth values between *completely true* and *completely false*. It was introduced in 1965 by Dr Lotfi Zahdek, then Chair of UC Berkley's Electrical Engineering Department, as a way of modelling the uncertainties of natural language. See Kosko (1993). In psychological terms, Pinker (1997: 101) explains that … "In many domains people do not have all-or-none convictions about whether something is true."

Gatekeeper. *Gatekeepers* in organisations are those who *directly control* a situation. They often control access to parts of an organisation or people within it, and are found in all functions and at all levels. Getting them on board is a principle, not a technique (Weisbord, 1987: 88-91). See 2.2. Note that in this dissertation, gatekeeper is taken to mean more than Andersen and Richardson (1997: 109) suggest. They use the term to describe a contact person within the target organisation. In this dissertation, a gatekeeper can be the same contact person but can be a person who overtly or covertly controls access to information, to people or can influence acceptance of management intervention processes. Also see *gatekeeper (modelling gatekeeper).*

Gatekeeper (modelling gatekeeper). *Modelling gatekeeper.* Andersen and Richardson (1995; 1997) use the term gatekeeper for this role. This role is filled by a person within, or related to, the client group who carries internal responsibility for the project, usually initiates it, helps frame the problem, identifies appropriate participants, works with the modelling support team to structure the sessions, and participates as a member of the group. Aware of system dynamics literature and practice but not necessarily a modeller, the modelling gatekeeper is an advocate in two directions: within the client organisation she speaks for the modelling process, and within the modelling support team she speaks for the client group and the problem. The locus of the modelling gatekeeper in the client organisation will significantly influence the process and the results. Also see *gatekeeper*.

Groupthink. A strong concurrence-seeking tendency that interferes with effective group decision making (Forsyth, 1990 : 490).

Heuristic. A *heuristic* is a higher order psychological adaptation, a useful mental shortcut, an approximation, or a rule-of-thumb for guiding search and enabling adaptive decision-making. Simple heuristics can be used singly and in combination to account for a great variety of higher order mental processes that may at first glance seem to require more complex explanation. This observation led Gigerenzer et al (1999) to formulate the basic idea of the *adaptive toolbox*: the collection of specialised cognitive mechanisms that evolution has built into the human mind for specific domains of inference and reasoning, including fast and frugal heuristics (Gigerenzer, 1999: 25-31).

Hierarchy. The principle according to which entities meaningfully treated as wholes are built up of smaller entities which are themselves wholes… and so on. In hierarchy, *emergent properties* denote the levels (Checkland, 1993: 314).

Human Activity System. A notional purposive system which expresses some purposeful human activity, activity which could in principle be found in the real world. Such systems are notional in the sense that they are not descriptions of actual real-world activity (which is an exceptionally complex phenomenon) but are intellectual constructs; they are ideal types for use in a debate about possible changes which might be introduced into a real-world problem situation (Checkland, 1993: 314).

Influence Diagram. An *influence diagram* is a list of factors in a problem, together with arrows and signs showing the relationship between them (Coyle, 1996: 31). The *influence diagram* has much more rigorous rules than the *causal loop diagram*, paying strict attention to differentiating *rate* and *level* variables.

Knowledge. The simple dictionary definition of *knowledge*, that is, knowing or familiarity gained by experience, is not sufficient for this thesis. Creating a precise definition of *knowledge* is difficult. So, what is knowledge is distinguished from what is not. *Knowledge* is a pluralistic concept. No one framework can capture its facets and its richness. It is not data, nor information. It exists only in human minds and cannot be stored directly or completely in computers or in any other medium. *Knowledge* cannot be communicated directly unlike data, and information, which can be. In this thesis, both cognitive mapping and concept mapping are used as intellectual devices with aims of representing and recording facets of knowledge. Churchman (1971) explains that knowledge and information are distinct entities; knowledge resides in the user of information and not in the collection of information; it is how the user reacts to the collection of information that matters. Jarvis (1999) comments that information becomes knowledge when it is understood or comprehended at a deeper level as a result of human mental activity involving perhaps the further analysis of information including association with other data or information. Such knowledge can lead to purposeful human activity, in particular decision-making.

Learning. *Learning* occurs when an actor in problem situation invents, then produces a solution. Learning has not occurred until a match, or mismatch, [between actual and desired states] is produced (Argyris, 1992: 8-9).

Level. See *stock*.

Leverage. *Leverage* is built on the notion that small, well focused actions can sometimes produce significant, enduring improvements, if they're in the right place. Tackling a difficult problem is often a matter of seeing where the high *leverage* lies (Senge, 1990: 64).

Leverage point. A *leverage point* is where a small difference can make a large difference. Leverage points provide kernel ideas and procedures for formulating solutions. Identifying *leverage points* helps us:

create new courses of action;

develop increased awareness of those things that may cause a difficulty before there are any obvious signs of trouble, and figure out what is causing a difficulty.

Modeller / reflector. This person focuses not at all on group processes but rather on the model that is being explicitly (and sometimes implicitly) formulated by the facilitator and the group. The modeller / reflector serves both the facilitator and the group. He thinks and sketches independently, reflects information back to the group, restructures formulations, exposes unstated assumptions that need to be explicit, and in general serves to crystallise important aspects of structure and behaviour. Richardson and Anderson stress that in their experiments, it was found necessary for both the facilitator and the modeller / reflector to be experienced system dynamics modellers (Richardson and Andersen (1995: 113-137). Also see *process coach, recorder, modelling gatekeeper, facilitator / elicitor*

Modelling challenge. Our methods and tools for modelling, optimisation, and control depend heavily on exploiting problems structure. Understanding the relationship and constraints underlying the problem structure enables predicting system behaviour as well as potentially controlling behaviour. Decomposing problem structure, associating first principles with the elements resulting from this decomposition, then recomposing these principles into an overall mathematical or computational model are typical steps of systems modelling. Frequently, this does not work. Understanding why and developing real insights into complex problems involves what Sage and Rouse (1999) describe as the *modelling challenge*. Meeting the modelling challenge is complicated by the fact that not all critical phenomena can be fully understood, or even anticipated, based on analysis of the decomposed elements of the overall system. Complexity not only arises from there being many elements of the system, but also from the possibility of collective behaviours that even the participants in the system could not have been anticipated (Casti, 1997).

Metacognition. This is seeing inside our own thought processes: the process of metacognition means thinking about thinking. Four elements of metacognition are most important:

being aware of memory and cognitive capacity limitations,

having the 'big picture' [a holistic view],

ability to self-critique, and

strategy selection (Klein, 1998: 158).

Metacognition is explained in greater detail by Forrest-Pressley, Mackinnon and Waller (1985).

Naturalistic Decision-Making. *Naturalistic decision-making* was formulated by Klein et al (1993) to explain how decision-makers formulate decisions. Klein's *naturalistic decision-making* model is based on extensive field work and differs from a *decision event* model in the following ways:

much effort is devoted to situation assessment or figuring our the nature of the problem;

single options are evaluated sequentially through mental simulation of outcomes; and

options are accepted if they are satisfactory, rather than optimal.

Also see *decision event model*.

Negative Feedback. *Negative feedback* is a form of circular causality which characteristically tends to produce a stable reaction, that is, a tendency to diminish or counteract a change in any one of its elements. For a more detailed explanation of the feedback phenomenon, see Richardson (1991) and Coyle (1996). Also see *positive feedback.*

Organisational learning. See *learning*, *single loop learning*, and *double loop learning*. In an organisational context, learning may not be said to occur if someone (acting for the organisation) discovers or invents a solution to a problem. Learning occurs when the problem is actually produced. This distinction is important because it implies that discovering problems and inventing solutions are necessary, but not sufficient conditions for organisational learning, noting that organisations exist to act and accomplish their intended consequence. Another reason this distinction is important is that significantly different designs, heuristics for action and criteria for success are used when individuals discover and invent concerning an issue than when they discover and invent in order to produce and outcome about the issue. See Argyris and Schön, 1978; Argyris, 1980.

Parameter. *Parameters* are factors that define an alternative and determine its behaviour. The value to which parameters are set restrict what results are possible to achieve within an alternative (Sage and Rouse, 1999: 938). *Parameter,* as used in this dissertation, means a determining characteristic, feature, or prominent factor. It is closely related to the mathematical definition of a *parameter* as a special variable because a parameter is a controllable factor that has a main role in determining the basic form and function of an alternative. This is like a *parameter* in a mathematical function or statistical distribution because the value to which a mathematical or statistical parameter is set determines the specific form of the function or the shape of the distribution.

Participatory Management. Participatory management encourages involvement of stakeholders at all levels in analysis of problems, development of strategies and implementation. Kurt Lewin had an important core principle: we are likely to modify our own behaviour when we participate in problem analysis and solution and likely to carry out decisions we have helped make (Weisbord, 1987: 89).

Polarity. In a *causal loop diagram*, *concept map* or *influence diagram*, signs adjacent to the arrows are used to indicate *polarity.* A plus (+) sign implies that a change in the variable at the tail of the arrow will cause a change in the variable at the head of the arrow in the same direction. …Similarly, a minus (-) sign implies that a change in the variable at the tail of the arrow will cause a change in the variable at the head of the arrow in the opposite direction. (Richardson, 1985: 159). In an alternate convention 's' (same) is used to represent positive *polarity* and 'o' (opposite) is used to represent negative *polarity*.

Policy. A *policy* is established as guiding rule(s) applied to a point in a system. This rule [, or set of rules,] is applied continually as time passes and even as circumstances change. It is critical to understand that *policy has two components*. The first is *structure*; the form of the equation and the corresponding set of links on the influence diagram. [The influence diagram describes most influential concepts, factors, or forces acting and the interrelationships between them]. The second is the *parameters* within a given structure. A *policy* specifies how actions should be taken in the information / action / consequences paradigm, noting an emphasis on the repetitiveness of the actions (Coyle, 1996; 222). Also see *pressure point*.

Positive feedback. *Positive feedback* is a form of circular causality, which acts as a growth-generating mechanism. The state of the system, such as one's bank balance, grows continually larger as interest payments act as the rate of change. This is sometimes called a virtuous circle, as opposed to a vicious circle, which arises when the balance becomes negative and one gets deeper and deeper into debt as interest is added to the debt. *Positive feedback* is quite common in managed and may be valuable as an engine of growth. In an engineering system, however, *positive feedback* is undesirable and is designed out, which is one reason why the mathematical techniques of control engineering are of little help in designing managed systems. For a more detailed explanation of the *feedback* phenomenon, see Richardson (1991) and Coyle (1996). Also see *negative feedback.*

Pressure point. A *pressure point* is a point at which a change intervention is applied. *Pressure points* carry an implication of an investment, or choice, which is made only once, after which the system will run under the influence of that choice. Naturally, one seeks to find the pressure points which will make [the system being studied] run in the most effective manner possible, so *pressure point analysis* is still *policy analysis*, albeit of a slightly different type. Equally naturally, there is no hard-and-fast dividing line between the different modes of analysis and, in practice, a given study may involve both types (Coyle, 1996; 222). Also see *policy.*

Process coach. This person focuses not at all on content but rather on the dynamics of individuals and sub-groups within the group. Richardson and Anderson have found it both useful and annoying that their process coach is not a system dynamics modeller; such a person can observe unwanted effects of jargon in word and icon missed by people closer to the field. The process coach tends to serve the facilitator; his efforts being largely invisible to the client group (Richardson and Andersen (1995: 113-137). Also see *modeller / reflector*, *modelling gatekeeper, facilitator / elicitor, recorder.*

Rate. A *rate* or *flow* in a system dynamics causes the value of a *stock* or *level* to change.

Recorder. Writing down or sketching the important parts of the group proceedings is the task of this person. Together with the notes of the *modeller / reflector* and the transparencies or the notes of the facilitator, the notes and drawings made by the recorder should allow a reconstruction of the thinking of the group. This person must be experienced enough as a modeller to know what to record and what to ignore (Richardson and Andersen (1995: 113-137). Also see *process coach, modeller / reflector, modelling gatekeeper, facilitator / elicitor*

Responsibilities Assignment Matrix. A *responsibilities assignment matrix* is a device for recording who is responsible for what. It contains a summary of specific responsibilities, normally as rows, and individuals or organisational elements as columns. Symbols are placed in the body of the matrix to represent the involvement of individuals as a means of fostering and recording their role in, and commitment to, strategy implementation (Turner, 1993: 142). In workshop or team situations, such as group model building, it may be useful to distinguish stakeholders, experts in aspects of the system being discussed, and members of an internal modelling team who will carry the technical work forward and record their negotiated and agreed responsibilities.

Root Defintion. A concise, tightly construction of a *human activity system* which states what the system is; what is does is then elaborated in a *conceptual model* which is built on the basis of the definition. Every element in the definition must be reflected in the model derived from it. A well-formulated root definition will make explicit each of the *CATWOE* elements. A completely general root definition embodying *CATWOE* might take the following form:

> A (…*O*…)-owned system which, under the following environmental constraints which it takes as given: (…*E*…), transforms this input (…) into this output (…) by means of the following major activities among others: (… … …), the transformation being carried out by these actors (…*A*…) and directly affecting the following beneficiaries and/or victims (…*C*…). The world-image which makes the transformation meaningful contains at leas the following elements among others: (…*W*…) (Checkland, 1993: 317).

Satisficing. *Satisficing* is a method for making a choice from a set of alternatives encountered sequentially when one does not know much about the possibilities ahead of time. In such instances, there may be no optimal solution for when to stop searching for further alternatives. *Satisficing* takes the shortcut of setting an adjustable aspiration level and ending the search for alternatives as soon as one is encountered that exceeds the aspiration level (Simon, 1956: 129-138; 1990: 1-19). *Satisficing* is a form of *bounded rationality*. For a detailed explanation of rationality see Gigerenzer, et al., 1999.

Single loop learning. *Single loop learning* is a term borrowed from electrical engineering or cybernetics where, for example, a thermostat is defined as a single-loop learner. The thermostat is programmed to detect states of ‘too cold’ or ‘too hot’ and correct the situation by turning the heat on or off. Whenever an error [difference, δ, between actual and desired states] is detected and corrected without questioning or altering the underlying values of the system (be it individual, group, inter-group, organisational or inter-organisational), the learning is single-loop (Argyris, 1992: 8). Also see *double loop learning*.

Situation Awareness. Decision-makers are drawn to certain situational cues and not to others because of their *situation awareness*. This pattern matching process happens all the time, and these responses to the environment are automatic. Situation awareness is one basis for what we call 'intuition': recognising things without knowing how we do the recognising (Klein, 1998: 33). Klein's claim is that situation awareness grows out of experience.

Shifting Loop Dominance. In a system described by two or more feedback loops, where at least one has negative polarity and at least on has positive polarity, over a period of time changes its growth or decay tendencies can occur. This is described as a shift in loop dominance. Shift in loop dominance is created by the differential equations, which describe loop behaviour. No outside influence causes the change. The shift is a consequence of the non-linear structure of the differential equations (Richardson, 1991: 33-34).

Stakeholder. A *stakeholder* is a person involved in, or affected by, the process of developing an organisational change or strategic intervention, or the outcome of that intervention. Eden and Ackermann (1998: 117-118) note that stakeholders need to be recognised for being associated with interactions that are dynamic and possibly unstable. Stakeholders are managed only as a means to pursuing strategic ends. Stakeholders are not treated as having rights, only as having power and interest.

State Variable. *State variables* are a collection of variables that we choose to monitor to inform us about the status of a system (Sage and Rouse, 1999: 939). The specific values chosen depend on why we want the information. Also see *variable*.

Strategy. Strictly speaking, 'strategy' describes 'generalship' and is literally the 'art of war'. In this dissertation, *strategy* is taken in a corporate sense to mean managing the disposition of resources, application of effort and creating conditions for the preferred way of doing business.

Stock. A *stock* or *level* is a simple conceptual device used in a system dynamics to represent parts of the system in which accumulation occurs.

Systemicity. *Systemicity* is a term used by Checkland (1999) to describe the complex, dynamic behaviour exhibited by systems, or systems-of-systems. Checkland does not suggest we attempt to contemplate whole systems, but that we acknowledge the complexity of the world and that the world is whole. The notion of *weltanschauung* is complementary to *systemicity*. Also see *weltanschauung*.

Systemic Structure. *Systemic structure* describes the web of interrelationships between factors at play which, have shaped or continue to shape the dynamic behaviour of a problem situation. The structure fundamentally affects behaviour: change the structure and the behaviour changes.

Systems Thinking. An *epistemology* which, when applied to human activity is based upon four basic ideas: emergence, hierarchy, communication and control as characteristics of systems. When applied to natural or designed systems the crucial characteristic is the *emergent properties* of the whole (Checkland, 1993: 318).

Variable. A *variable* is a measurable quantity one chooses to monitor as the system under investigation operates. Variables are likely to change once the system is in operation, or a simulation is run. Also see *state variables*.

Weltanschauung. The German word *weltanschauung,* mainly used by Checkland, stresses the importance of accommodating varying perspectives about a problem. Depending on the context, *weltanschauung* means a world, or worldly, view; or what is within our view or perspective at a point in time, current affairs. Also see *systemicity*.

'Wicked' Problems. *'Wicked'* is used to characterise problems, which are complex, dynamic and systemic. They have been described as be insidious, growing like a cancer. When we become aware of them, we may find they are difficult to resolve. We might make what we believe to be a valid change, implement what appears to be rational and logical policy or strategy, only to find we still have problems. They change form, adapt, reorganise, and reappear as a mutation.

CHAPTER 1: INTRODUCTION

Synopsis

Understanding complex, dynamic 'wicked' problems where cause and effect are not proximate, or where feedback exists, can be problematic for us. Many 'wicked' problems are critically important, costing millions of dollars and threatening lives. They deserve our careful attention.

This chapter suggests that whilst various techniques are used for analysing such problems, their application is still more of an art than a science. Many analysts argue that the dynamics of these problems cannot be fully understood unless they are modelled using quantitative techniques. But, there is growing support for the use of qualitative modelling, particularly in problems where 'soft' variables are involved. This chapter describes the need for qualitative and quantitative modelling, identifies a disjunction between the two, and suggests that integrating them could bring significant benefits.

This chapter introduces the concept mapping technique used throughout this dissertation. A short tutorial, given in Annex A, is used to explain the fundamentals of concept mapping, how it is applied, and to show the way it is used in this dissertation may not be identical to its use by other researchers.

Many of contemporary man's achievements are impressive. Each day we are reminded of dramatic advances in the speed of microchip processors, unravelling of complicated medical mysteries like sequencing the human genome or discovering what causes cancer, development of new telecommunications and information technologies, and the like. Amongst the most memorable of contemporary undertakings commenced with an announcement by President John F. Kennedy that before the end of that decade, the 1960s, the US would land a man on the moon and bring him back alive. This was an awe-inspiring promise. However, without detracting from this impressive undertaking:

a. The laws of physics that constrained how a moon landing might be achieved were very well understood. Professor Stephen Kline, in his 1995 seminal work on multi-disciplinary thinking observes that Newton's 'laws' form an *entire invariant paradigm* with about as much assurance as humans know about the world. The National Aeronautics and Space Administration (NASA) was dealing with what it knew and understood. No new physical laws were discovered as a result of this project.

b. With few exceptions, the behaviour of systems was predictable: characteristically they were deterministic. Aspects not well understood were thoroughly investigated through extensive testing and modelling. For example, man's physiological response to high acceleration during launch and low gravity on the moon's surface were subjected to extensive research.

c. When rated according to Kline's *Complexity Index*, defined below, the systems involved were only moderately complex.

Consequently, theories for entire systems could be constructed, verified, and validated. However, there is a class of problems that are both more common and more complex, but not as well studied. They are addressed in this thesis.

1.1 Complexity and the Complexity Index

Problems can differ significantly in their complexity. We need to understand the impact this can have. The following explanation is intended to correct some of the vagaries in the use of the terms 'complex' and 'complexity'. To provide the reader with a useful measure, the *Complexity Index*, denoted C, defined by Kline (1995) is used. C is defined in terms of three other quantities:

V = The number of independent *Variables* needed to describe the state of the system.

P = The number of independent *Parameters* needed to distinguish the system from other systems in the same class.

L = The number of control *feedback Loops* both within the system and connecting the system to the surroundings.

The upper and lower values of *C* are defined as:

$$V + P + L < C < V \, . \, P \, . \, L$$

noting that when L = 0, or V and P both have low values, *C* is taken to be V + P + L. For a particular system, the location of the value of *C* between these upper and lower bounds will depend on the degree of 'connectedness' within the structure of the system and between the system and its surroundings (Kline, 1995: 49-51). Rather than attempting to make exact estimates of *C*, Kline makes rather crude one-sided estimates using inequalities. That is sufficient for our purpose. *C* is derived as demonstrated below.

The typical systems analysed in classes in physics, chemistry, and in analytic problems in beginning engineering classes have no control theory feedback loops; so L = 0. Kline explains that, in such beginning problems we fix the values of the parameters and study a particular case. For these systems, typically V = 1, 2, or 3; thus we write:

$C_A < 5$, where subscript $_A$ denotes the class of systems under consideration.

Kline further explains that Class *A* systems include deflection of simple structural members; the motion of pieces of matter under prescribed forces; the properties of chemical solutions; the path of light rays through gases or transparent solids; behaviour of simple semiconductors, and many other systems consisting of inert, naturally-occurring matter and energy in the sense of physics (Kline, 1995: 52).

1.2 Everyday Systemic 'Wicked' Problems

Many everyday problems are much more complex than these Class *A* examples. Professor Steven Pinker (1997) observes that many problems we face today are conceptually more 'difficult' than the problem of putting a man on the moon…

> … problems that we humans solve as we see and walk and plan and make it through the day are far more challenging than landing a man on the moon or sequencing the

> human genome (Pinker, 1997: 4).

The everyday problems we know to be conceptually more 'difficult' are those that are complex, dynamic and systemic. In this dissertation, interest is focused on one particular class of ubiquitous problem, a class of 'difficult' problem, which Horst Rittel (1972) describes as 'wicked'. The description 'wicked', and others very like it, are used by a number of highly regarded authors because they describe such problems very well. Richard Mason and Ian Mitroff refer to the behaviour of 'wicked' problems:

> … like the head of a hydra… an entangled web of tentacles… the more you attempt to tame them, the more complicated they become (Mason and Mitroff, 1981: 10).

In his 1996 prize-winning book on *Group Model Building*, Professor Jac Vennix uses the term 'messy' to describe this same class of problems. Vennix observes that 'messy' problems are often quite intangible. Attempting to establish a statement of an 'objective function', so familiar in operations research, is totally inappropriate. Further, Vennix notes that 'messy' problems are situations defined by some people as 'problems'. Frequently there is disagreement about whether there really is a problem. If the existence of a problem is agreed, there is often contention about its nature.

'Wicked' or 'messy' systemic problems:

a. involve strongly-coupled interrelationships between numerous factors;

b. involve feedback loops where there is:

    (1) *latency* produced by the accumulation of delays in material or information flows;

    (2) *variable delay* – delays affected by chance events ; or

    (3) *variable loop dominance* – influence may switch from one feedback loop, or set of loops, to others at a different time, based on the history of responses to the feedback.

c. contain facets of complexity produced by the coexistence of man and technology;

d. have governing laws that are 'fuzzy' and have descriptions of behaviour that often involve 'fuzzy logic';

e. involve the holding of disparate views by stakeholders; and

f. have behaviour that may not be easy to replicate and, so, trying to manage these problems often creates uncertainty, ambiguity, and conflict.

These ‘wicked’ problems are confounding to diagnose. This is discussed in Chapter 5.

Organisational development researchers and practitioners, Australian Fred Emery and British Social Scientist Eric Trist (1965: 21-32) noted that these problems exhibit ‘environmental connectedness’. Mason and Mitroff (1981: 6) note that this is just one characteristic that contributes to ‘organised complexity’, the form of behaviour where…

> … deviations in one element can be transmitted to other elements … in turn these deviations can be magnified, modified, and reverberated so that the system takes on a kind of unpredictable life of its own.

When faced with complexity, where connected elements are tightly woven together, we find we have no theory for entire systems. Further each ‘wicked’ problem is unique: being called upon to take some form of effective remedial action is a substantial challenge. ‘Wicked’ problems are pervasive and affect our lives in profound ways. Small and large corporations, Governments at all levels, and society generally, continually struggle to create strategies to overcome ‘wicked’ problems, such as:

a. how to limit the supply and use of illicit drugs, so reducing consequential and detrimental effects on society;

b. how to create health management strategies which minimise the impact of growing resistance of bacteria to antibiotics; and

c. how to implement effective and lasting organisational, or social, change.

Regardless of their size, ‘wicked’ problems are always difficult to manage. Some cost many millions of dollars: some also create a legacy of lost human life. Unfortunately, our track record in addressing such problems is not as good as it might be. One reason is that we are challenged when it comes to understanding complex, dynamic, systemic problems. Why this is so, and how we might do better, is addressed in this thesis.

1.3 When ‘Single Loop’ Learning Works and When it Does Not

‘Single Loop’ learning is a term coined by Professor Chris Argyris to describe an inferior, shallow form of understanding. Argyris (1991: 99-109) uses the following analogy to explain the difference between this form of learning and the in-depth form, ‘double loop’ learning:

> … a thermostat that automatically turns on the heat whenever the temperature in a room drops below 68 degrees is a good example of single-loop learning. A thermostat that could ask, “Why am I set at 68 degrees?” and then explores whether or not some other temperature might more economically achieve a goal of heating the room would be engaging in double-loop learning.

Argyris observes that highly skilled professionals are frequently good at single-loop learning but not so good when it comes to double-loop learning. After all, he argues, they have spent much of their lives acquiring academic credentials, mastering one or more of a number of intellectual disciplines and applying those disciplines to solving real-world problems. But ironically, this very fact helps explain why professionals are often so bad at double loop-learning. Put simply, because many professionals are successful at what they do, they rarely experience failure. And because they have rarely failed, they have not been forced to critically examine their decisions. This thesis seeks to find ways to correct the failure to learn described by Argyris. Failure to learn was found to be a recurrent theme in cases studied at Chapters 3 and 4.

Professor John Sterman (1994) observes that few people can write, let alone solve, the equations of motion for a bicycle. Yet, Sterman argues, a child learning to ride a bicycle does so with little regard to the complexity of the task. Initially, this seems contradictory to what Argyris argues, but it is consistent. A child does not need to be taught anything about the laws of physics; no formal lessons about momentum, friction, precession, action and reaction, torque, or moments of inertia. However, all of these are at play when a bicycle is being ridden. The child learns through incremental investigation, experimentation and trial-and-error. But, for this to happen, sensory feedback must be immediate or very proximate. Under conditions where system response is always the same, learning can be rapid. A child who turns the handlebars too suddenly when riding on a slippery surface will soon discover the pain of skinned knees. In this instance, learning is immediately reinforced, but this is not double loop learning.

It is highly significant that when it comes to ‘wicked’ problems, cause and effect tend not to be proximate, either temporally or spatially, and the influences of several causes may combine in different ways to produce similar effects. This creates confusion in our minds, or misinterpretation of cause and effect. Such confusion, or misinterpretation, is the product of dysfunction between observed effect and actual cause. A major contributor to this dysfunction is systemic feedback. Our childhood learning and even our professional experiences are very likely to fail us when we face systemic feedback situations. Indeed, under these circumstances, human ability to understand, to learn and to predict behaviour, suffers serious overmatch.

1.4 Problems in Dealing with Feedback

When it comes to situations where feedback exists, Sterman observes:

> People cannot simulate mentally even the simplest possible feedback system, the first order positive feedback loop. The differential equation $dy/dx = gx$ yields pure exponential growth $x = x_0 \exp(gt)$. Such positive feedback processes are commonplace, from compounding of interest to the growth of populations… [yet] people significantly underestimate exponential growth, tending to extrapolate linearly rather than exponentially (Sterman, 1994: 309).

Human mental simulation capacity is very limited: we can cope with problems involving complexity described by $C < 5$. Linda Sweeney and John Sterman (2000) demonstrate human limitations in performing graphical integration of simple dynamic problems, a task requiring basic mental simulation skills. Kline (1995) argues that many of the problems we face have complexity in the range $10^6 – 10^{13}$. We have little hope of coping with such problems. Traditionally, we bound the problem space in ways that dramatically reduce the complexity and seek support from dynamic analysis tools that compensate for human cognitive shortcomings. But to do this most effectively, we may need to change the ways we approach ‘wicked’ problems.

Professor Geoff Coyle (1977; 1996) systems dynamicist for more than 30 years and first recipient of the System Dynamics Society’s Lifetime Achievement Award, observes that we are frequently ignorant of the mechanisms responsible for systemic feedback. Richardson (1991), Dr Mark Paitch in Paitch and Sterman (1993), Dr Jack Homer (1996), and Sterman, (1994; 2000) and many other leading researchers make similar observations.

Most of us have spent a lifetime relying on trial and error rather than building comprehensive understanding of feedback mechanisms that produce systemic behaviour. Consequently we run the risk of making inappropriate judgements in dynamic situations. System dynamics pioneer, Professor Jay W. Forrester and other leaders in the field are united in acceptance of the evidence that man is not well equipped to deal with the unpredictability of complex, dynamic systems (Coyle, 1977: 1996; Forrester, 1971; Homer, 1996; Sterman, 1989: 1994: 2000).

Further, it is the author's observation both as a researcher and consultant to government and industry, that managers and executives seem to accept risks associated with having limited cognitive capability. One consequence is that many systemic problems are addressed using what amounts to be little more than trial and error.

In their 1994 book 'Modeling for Learning Organizations', Professor John Morecroft and Sterman make a compelling case for experimentation in a virtual world where consequences of failure are insignificant, but where benefits derived from double-loop learning are very real. This thesis considers ways of enhancing that double-loop learning regardless of the modelling being qualitative or quantitative in nature. It is argued that effective double-loop learning is the critical outcome.

1.5 Wise Uses of Qualitative and Quantitiative Modelling

It has long been argued that to understand the dynamics of complex systems, quantitative models are essential. Ogata (1992) and Richardson (1991) give many examples of complex dynamic systems that must be modelled in a quantitative way for a full understanding of their behaviour to be developed. The closer these systems are to the 'hard' end of the scale, the stronger this argument is, and the easier it is to sustain.

However, many 'wicked' problems contain 'soft' variables. An example of a soft variable is 'drug availability' in the illicit drugs problem, Coyle and Alexander (1997) and Chapter 11. Having to deal with soft variables makes quantification difficult. System dynamics practitioners now have more than 40 years experience in simulating circular feedback systems. Dr Peter Senge in his 1990 seminal book on systems thinking argued that it is both feasible and practical to take that experience and employ it in qualitative analysis of problems involving circular, systemic feedback. Taking this approach brings attendant problems, some of which were identified by Richardson (1996): these will be addressed in this thesis. The problems to which quantitative modelling applies are at high levels of aggregation: in general, they are strategic problems.

1.6 Complex Strategic Problems

The problems this research addresses are classified as strategic, not because of their global nature, or war-fighting context, but because of the level of impact they have on organisations. Strategic problems:

a. as Eden and Radford (1990) observe, have wide organisational significance, and inter-organisational ramifications;

b. are complex, according to Kline's definition (Kline, 1995) and, so, may be 'wicked' according to Rittel's definition (Rittel, 1972);

c. are confounding because the actions taken as a remedy may produce inadvertent and worrying ramifications (Eden and Radford, 1990; Forrester, 1971; Sterman, 2000);

d. represent dilemmas where there is unlikely to be any portfolio of actions that will be correct (Eden and Radford, 1990; Rittel, 1972);

e. involve remedial strategies that are seen as practically irreversible, and often involve a shift in organisational culture (Eden and Radford, 1990) though this is frequently unachievable; and

f. generally involve the non-routine development of commitment and ownership by key members of the organisation, because issues are non-routine and members of the decision-making group will have both complex and disparate views about the nature of issues (Eden and Radford, 1990).

A detailed characterisation of 'wicked' problems is at Chapter 5.

Much of the resultant debate about strategy and strategic decision-making stems from:

a. Real-world problems are frequently stochastic, rather than deterministic, in nature.

b. Rigorous analysis is unpopular among managers (Nutt, 1989). It can be slow and inconclusive, and often it is simply not trusted.

c. It can be difficult to find 'hard' answers to 'soft' problems.

d. Strategies for solving real-life problems come with no guarantees. Regardless of how well they are formulated, strategies always contain risk. The consequences of producing inappropriate strategies need to be taken into account along with, for example, an assessment of risk of allocating too little time to problem conceptualisation, see 2.1, or strategy development activities. Risk is discussed at 4.10, 4.11, 5.1 and 11.1. Chapter 6 offers principles of method for addressing complex strategic problems.

e. Confidence in predicting success of an intervention may be low: correcting an obvious problem can have unintentional adverse effects in a related area.

f. Changes often occur between the time a strategic decision is taken and implementation, thereby rendering the intervention less effective, or even ineffective.

g. Many systemic feedback mechanisms involve variable, or indeterminate, delays. Consequently, cause and effect are not proximate: causality is frequently attributed to an inappropriate cause or causes.

h. Strategy implementation being hampered by conflict among stakeholders.

i. Stakeholder resistance to change.

It is assumed that developing effective strategies, and fostering development of effective decision-making skills, are primary goals to which organisations aspire. In reality, there are many barriers to achieving these goals. Individual and organisational learning are often hindered, as brought out in later chapters.

Our tasks of understanding and managing strategic problems are frequently confounded because these problems comprise large numbers of factors interacting in ways that are deliberately or inadvertently masked. Masking can be the product of many factors including organisational hierarchies, culture and politics. This masking contributes significantly to uncertainty, ambiguity, mistrust and conflict. Further, strategic problems change over time. They involve vicious cycles of feedback and delay. They present exactly the situations with which the human mind is least capable of dealing.

There is little evidence that a common understanding of the nature of complexity exists. So, the early chapters of this dissertation review the fundamental nature of strategic problems. The reasons why such problems present decision-makers with detail and dynamic complexity; why uncertainty, ambiguity, and conflict so often result; ways of improving thinking, problem conceptualisation, analysis, decision-support, decision-making, and strategy development are investigated in the context of executive decision-making.

1.7 Need for an Action Research Approach

It was not possible to undertake a literature review as a compartmented body of work, completed in its own right before commencing the main research activities. In part this is because our understanding of complexity and complex problems is evolving, reflected in recent contributions to the literature. In greater part, it was found necessary to take experience from the case studies of Chapters 3 and 4 to redirect ongoing searches of the literature. In turn this led to charting new directions for this research, refinement of basic propositions, re-design of case applications, and so on. This is the nature of action research. An idealised representation of the process of action research (McNiff, 1988) is depicted graphically at Figure 1-1, below.

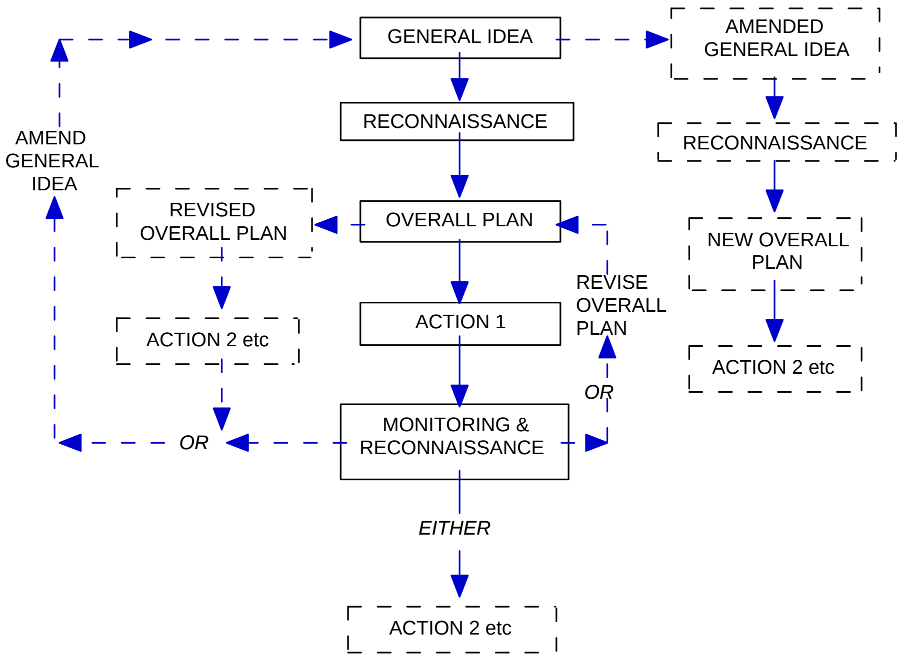


Figure 1-1. Idealised Representation of the Process of Action Research

A general idea, motivated by identification of a shortcoming or need to rectify an extant problem leads to generation of a plan of action. Development of the plan is informed by reconnaissance of the problem space. Sequences of development of plans and implementation follow. Action is taken and results are monitored. These are used to inform adjustments to the general ideas upon which earlier plans had been developed. Extent of success achieved determines the basis upon which subsequent plans are developed. In research involving organisations, the subjects, stakeholders in the consequences of plan implementation, must be closely involved. The greater the involvement, the better the opportunities for shared learning experiences. In a research context, the veracity of courses of action can be difficult to establish. However, propositions and hypotheses are repeatedly created and tested, with high levels of involvement of the research subjects, see 2.2. Modelling, qualitative or quantitative, and simulation play important roles in the processes of developing and testing hypotheses. Cycles of creating and testing hypotheses are fundamental to action research, action learning, and the way the research described in this dissertation was conducted. See 2.11, 2.13 2.16, 2.23, 2.24, 5.5, 5.12, 6.4, 6.11, 6.15, 6.22, 7.16, 7.18, 9.3, 9.11, 9.21, Chapters 11 and 12. The significance of this is that it forms the basis of the problem-solving method described at Chapter 6 and demonstrated at Chapter 7.

It will be demonstrated in Chapters 8, 9 and 10 that research subjects were always involved in validating the content of records created during interviews and workshops, except under circumstances described at 9.6 and 9.7, where a modified procedure was needed.

1.8 Strengths, Weaknesses and Alternatives to Action Research

The laboratory for the work described in this thesis was the world of project implementation in the Australian Defence Organisation and in the private sector. This presented all the difficulties of working with people and organizations. Competing with, or contributing to, pressures of daily work, to gain the attention of the subjects of the research is the nature of action research. The action research methodology used here derives from Kurt Lewin (1946), essentially an externally initiated intervention designed to assist a client system, functionalist in orientation, and prescriptive in practice. Guides to the practical implementation of action research were taken from McNiff (1988) and Revans (1982). The strengths, weaknesses and alternatives to the action research as applied to this body of research are:

a. Strengths. Conducted properly, action research can be most valuable in producing lasting change in organizations, through modifying the ways people think and act. In large part, 'conducted properly', means the client group is continually and comprehensively engaged. That was the aim of both the research activity and IISD.

b. <u>Weakness</u>. To engage the client group to produce the necessary learning and change demands the careful selection and use of intervention techniques, which do not threaten the client group. Often the very presence of a researcher or research team can be threatening, although the Hawthorne Effect is a positive one observed in early US practice with General Electric. Problems associated with engaging the client groups are described in each of relevant chapters, *viz* Chapters 8, 9, and 10. In the context of this research, the cases studied at Chapters 3 and 4 could only be conducted 'after the fact' and involvement of the client group was necessarily, but unfortunately, very limited. Strictly speaking, these were not action research activities, because of limited client involvement. However, lessons were drawn from these cases and used to guide the conduct of subsequent action research activities, the sequence in which this research was conducted being outlined at Figure P-2. This did not detract from the overall action research approach.

c. <u>Alternatives</u>. Alternatives to action research would have involved designing, setting up and conducting learning laboratory experiments in which client groups would be exposed to artificial scenarios and their actions measured. It was considered this would be impractical given that the extensive resources needed were unavailable. Learning laboratories, such as those established at universities having a strong focus on action research and action learning, MIT being but one example, are unable to replicate the richness and diversity found in the real world organisational strategic decision-making environments, such as those investigated here.

1.9 Understanding and Learning Facilitated by Modelling and Simulation

A consistent theme throughout this dissertation is that effective understanding and learning are pre-cursors to effective decision-making. When it comes to promoting understanding of complex, dynamic, systemic problems, computer modelling and simulation can be highly valuable aids. Vennix, Andersen, and Richardson (1997), observe that studies on the impact of computer models on policy making have convincingly revealed model building is an important aid in building conceptual skills. They recognise that most learning takes place in the process of actually building the model, rather than after the model is finished. Forrester (1971) makes a similar point, that modelling should be seen as a continuing companion to, and tool for, the improvement of judgement and human decision-making. The observations by Vennix, Andersen and Richardson, and Forrester's suggestion are taken as founding propositions upon which this thesis builds. So, for understanding and learning to be effective, and for action learning to occur, decision-makers must be involved as closely in the model building process as their busy schedules permit.

1.10 Qualitative Versus Quantitative Analysis

Building quantitative system dynamics models is not seen to be the best approach in all cases. Building computer models takes time and can consume considerable resources. Whatever decision support is provided, it must fit within the decision-maker's decision cycle. See 2.20. Factors which might impact upon the extent of analysis conducted include limited access to key stakeholders or subject matter experts, as well as time constraints.

Promotion of systems thinking as a discipline by its advocates appears to be based on a set of inferences that extensive research and experience underlies the specification of archetypes, that archetypical problems are readily recognisable, and devising remedies is rather routine. Significant findings from cases studied as part of this research include repeated failure by managers and decision-makers to recognise emerging patterns of systemic behaviour. If, in fact, the managers involved did recognise archetypical behaviour, they took little or no corrective action: evidence suggests they failed to appreciate potential consequences of what was developing around them. There is clear evidence of failure to assess and manage relevant risks. 'After-the-event' analysis of the cases studied at Chapters 3 and 4 suggests that a 'reasonable person' who had a reasonable level of situational awareness should have recognised the most dominant influences in emerging problems. This research suggests managers routinely fail to recognise the archetypes espoused in the literature as underlying so many dynamic, systemic problem situations.

In 2000, Erling Moxnes recognised by the System Dynamics Society for his outstanding research paper on bio-economic sustainability. This was an impressive piece of research into a complex problem. Writers such as Senge and Kim would lead us to believe we should easily and reliably recognise what Moxnes investigated as an archetypical *Tragedy of the Commons* problem. Indeed it was archetypical. But, it is considered extremely unlikely that when he looked at the problem for the very first time that Moxnes exclaimed… 'Eureka – Tragedy of the Commons!' So it is with complex problems we encounter as researchers: for quite some time we do not know exactly what we are facing. Only after detailed analysis do we become sure. Just as a physician diagnosing a patient's illness, we have to run a series of definitive tests. In the absence of a definitive test regime being available to us, we need to eliminate certain possibilities before pronouncing a diagnosis.

Unlike what is suggested in the literature, Sterman (2000) is an example, and so frequently taught in schools and universities, qualitative and quantitative analytical techniques are disparate: they are not integrated. This creates problems both in teaching and learning the system dynamics 'method'. It is only after detailed understanding of quantitative modelling has been developed, that qualitative modelling can be fully appreciated. The disjunction between qualitative and quantitative modelling is recognised when it is accepted, as Dowling, MacDonald and Richardson (1995) observe, that many practitioners would find it difficult to build formal models of systems thinking archetypes. Yet, qualitative methods, systems archetypes in particular, appear as the first stage of many system dynamics courses. Care is needed to avoid proceeding from the general to the specific, that is, from the archetypical causal loop diagram to a specific problem: such is <u>not</u> a scientific method.

Historically, system dynamics pioneers used very few qualitative techniques. Now, there is a growth in the popularity of qualitative methods. An increasing number of researchers are suggesting that many systemic problems can be addressed using strategies developed from qualitative analysis. They include Coyle (1983; 1984a; 1984b; 1985; 1996), Coyle and Alexander (1996), Kwahk and Kim (1999), Kim (2000), Wolstenholme (1985), Wolstenholme and Coyle (1983). Coyle (1997) explains:

> The concept is that formulation and study of an influence diagram can often be a useful exercise in its own right. Sometimes, a given problem is effectively "solved" in the sense that the insights from the diagram are so convincing that managers are prepared to act on them without a quantified analysis. In other cases… uncertainties in the numerical data are so great that a quantified model may contain such uncertainties and inaccuracies that it is not worth the effort of building (Coyle, 1997: 206).

In his introduction to Richardson (1985), Sterman observes that in all the successful applications of qualitative methods, the analysts have had extensive experience in quantitative modelling. Noting this qualification, it is my hypothesis that effective interventions can be built without necessarily resorting to computer modelling.

However, work is needed to identify just when qualitative modelling is appropriate. Strategies and policies are built on qualitative bases every day in government, industry and commerce from the highest levels, in Parliament and in the boardroom. It takes place through every level of management.

The success of 'qualitative' strategy development is dependent upon:

a. high levels of skill in identifying the relevant causal influences;

b. determining how these causal influences work in concert to produce the observed patterns of behaviour;

c. determining which of the influences are most dominant, and how dominance changes over time; and

d. developing and testing the efficacy of options for applying pressure in the form of management policy, or strategy, to these points.

This thesis seeks to identify ways of adding rigour to qualitative modelling and, as far as it is appropriate, integrate qualitative and quantitative modelling techniques.

Rigorous qualitative analysis does not flow naturally from systems thinking and recognition of causal loop diagram archetypes, such as suggested by Senge (1990). Detailed understanding of a problem situation, and likely remedial strategies, must come from empirical analysis in conjunction with an appreciation of *systemicity*, that is, the characteristic behaviour of systems and systems-of-systems, and the fundamental quantitative foundations underlying qualitative archetypical descriptions.

This investigation starts with consideration of:

a. how managers think and decide, noting influences such as:

   (1) bounded rationality;

   (2) human cognitive limitations;

   (3) organisational culture and politics;

   (4) the extent to which decision-makers appreciate risks, whether they are risk averse or risk takers; and

(5) how decision-makers are to make decisions in the absence of detailed information.

b. executive trust in decision-support systems, and

c. considerations of likelihood and consequence of:

(1) incorrectly diagnosing the attendant problem, then developing remedial strategies to correct what is, in effect, the wrong problem;

(2) diagnosing the problem correctly and developing effective remedial strategies;

(3) diagnosing the problem correctly, but failing to develop effective remedial strategies;

(4) diagnosing the problem correctly, developing effective remedial strategies, then not having these implemented; or

(5) doing nothing.

Over the past 15 years many differences of opinion have been expressed in *System Dynamics Review* regarding the application of qualitative system dynamics and quantitative simulation modelling. Some of those opinions were introduced above. Coyle's (2000) article confirms that the issues remain unresolved, asking: 'how much value does quantified modelling add to qualitative analysis?'… put another way… 'qualitative modelling may be imperfect but is quantification always better?' This will be revisited at Chapter 12. Whilst the research described in this dissertation does not seek to settle the long-running qualitative *versus* quantitative debate, *per se*, it recognises the issues, and it is hoped, advances the discussion through rigorous analysis.

This research seeks:

a. effective ways of tapping the minds of decision-making managers, to gain insights into how they think, decide, and develop strategies to be applied within their domains of action;

b. tools and techniques to aid analysis of causality underlying strategic problems;

c. intuitive ways of thinking, conceptualising, and fostering dialogue about strategic problems;

d. techniques for communicating ideas about systems;

e. ways of depicting systemic structure and behaviour;

f. ways of replicating and predicting how systems produce change over time;

g. development of strategies to overcome complex and dynamic systemic problems; and

h. ways of achieving a high probability of successful implementation of chosen strategies.

A tool and techniques designed to bridge the gap between qualitative and quantitative analysis are demonstrated at Chapter 11.

1.11 Iterative and Interactive Strategy Development

This dissertation explains the theoretical basis for, and practical application of a new framework, Iterative and Interactive Strategy Development (IISD) which has been developed to help in addressing strategic problems. It exploits recent advances by leading researchers and practitioners in strategic decision-making. It selectively uses compatible techniques which facilitate knowledge elicitation, systems thinking, computer-based decision-support, system dynamics, and group decision-making. The last is attributed to organisational change pioneer Kurt Lewin and anthropologist Margaret Mead who worked together in the United States during World War II. Together they pioneered participative management. The power of participative decision-making is profoundly important. Group decision-making has been exploited by Vennix (1996) in his *Group Model Building* strategy development intervention.

IISD was formulated in the early stages of this research, documented during the latter part of 1997, and published in 1998 (McLucas, 1998). Publication occurred at the same time as Eden and Ackermann's *JOURNEY* was published (Eden and Ackermann, 1998). The two are very similar, both as problem-solving frameworks and in the knowledge elicitation and problem conceptualisation tools they employ. However, whilst IISD development occurred in the light of, and drew on Eden and Ackermann's earlier published work, it is independent of their 1998 formulation.

IISD starts from the point where it is clear that something is wrong even though there may not be unanimous acknowledgment among stakeholders that a ‘problem’ exists. IISD focuses on:

a. tactics to bring about better understanding;

b. identifying and conceptualising the ‘right’ problem;

c. analysing the effects alternate strategies might have; and

d. how to develop consensus and commitment among stakeholders to enact a chosen strategy.

In addition to systems thinking and system dynamics, IISD accommodates tools and techniques such as concept mapping and analysis of stakeholder perspectives into an integrated framework. Also central is the notion that model building, verification and validation require a joint effort by decision-maker and analyst or consultant. IISD is not offered as an optimised methodology, rather it is an attempt to present a broadly applicable, continually evolving decision-support framework designed to foster individual and organisational learning. It aims to provide a practical methodology culminating in implementation of effective strategies.

The conceptual foundations and principles of method which form the basis for IISD are explained at Chapter 6. The need for IISD was identified and its scope clarified as a result of the case studies in Chapters 3 and 4, case applications at Chapters 8-10 and literature review spanning fields of systems thinking, decision analysis, system dynamics modelling and simulation. The impact of related disciplines such as cognitive psychology, group dynamics, and organisational learning were considered.

1.12 System Dynamics to Aid Understanding of Dynamic Complexity

The foundations of system dynamics modelling were established nearly 40 years ago and there is general agreement among researchers and practitioners that system dynamics modelling can provide valuable insights into behaviour of complex, dynamic systems. Modelling can significantly enhance understanding, for those closely involved in developing the models. See Chapter 10. It can be valuable in facilitating the development of strategies and selection of the more promising ones.

Whilst system dynamics modelling is a powerful technique, its application suffers in a number of critical areas. The first is problem conceptualisation. Many system dynamics modelling efforts address the wrong problem or model systems rather than modelling problems. Professor Peter Checkland, originator of Soft Systems Methodology (SSM), in his 30-year retrospective on SSM (1999) makes the point that we must approach systemic problems with a clear appreciation of *systemicity*, the systemic behaviour of systems, or systems-of-systems. We need to investigate and understand this *systemicity*, and bound the problem space correctly before setting out to solve the problem. In his classic 1966 work on management cybernetics, the application of control theory to the management domain, Professor Stafford Beer provides several operational analysis examples of verification errors, that is, addressing the wrong problem. Another error made in system dynamics interventions occurs when considerable effort is expended developing highly sophisticated models, which are not understood by decision-makers, with the result that meaningful strategies are neither developed nor implemented. See Chapter 10.

When it comes to verification and validation, system dynamics modelling practice still seems to be more art than science. In their rush to build models to demonstrate the relationship between systemic structure and behaviour, students routinely overlook the need for validation. Verification is directed at ensuring the right problem is addressed, that the internal construction of the model is correct and that the variables relate correctly, whilst validation is directed at ensuring models replicate observed real-world behaviour. Coyle (1999) highlighted the absurdity of conclusions drawn from system dynamics when logic and structure are flawed. In system dynamics, validation, in terms of establishing truth is problematic. It is suggested that poor system dynamics practice, especially in terms of validation, as far as validation is possible, is carried through to professional consulting. Building valid system dynamics models requires a structured approach with discipline similar to that needed to build reliable, quality software.

Far too often, insufficient attention is paid to parametric values for which a model remains valid (Coyle, 1999). Consequently there is real risk that models are invalid or may behave in a chaotic manner; the latter occurring if parametric values exceed thresholds for which the model has been validated. Exposing a decision-maker to poor quality models militates against acceptance of system dynamics as a tool for predicting systemic behaviour and is likely to produce misleading conclusions in an environment where learning is paramount.

Overcoming such weaknesses requires diligence and a systematic approach involving:

a. adherence to the scientific method, as noted by Homer (1996);

b. application of a problem-solving methodology, as explained in this dissertation;

c. rigorous, progressive verification and validation of models; and

d. comprehensive testing of the range of parametric values for which model behaviour remains stable and replicates observed behaviour.

1.13 Concept Mapping

Both cognitive and concept mapping have been used extensively as analytical tools. The difference between cognitive and concept mapping is explained at Annex A and in the Glossary. Briefly, concept mapping enables:

a. the presentation of large amounts of information and complex interrelationships in a single diagram, on one sheet of paper, or a small number of sheets;

b. replacement of dozens of pages of text by relatively intuitive, easy-to-read diagrams; and

c. presentation of information in a highly concentrated form.

An overview of cognitive and concept mapping techniques is provided at Annex A.

Underlying this thesis is the observation that quantitative descriptions are applicable only to certain classes of problems, whereas all problems may be described in qualitative terms. Concept mapping is only one way of revealing the underlying nature of problems. Alternate methods that might have been used are described at 6.23, 6.25, and 7.6. The choice of concept mapping was heavily influenced by considerations of cognition and decision-making, described at Chapter 2.

1.14 Purpose of Mapping

Purpose of mapping, and similar techniques, include:

a. bringing to the surface those assumptions people have about the focal problem (Mason and Mitroff, 1981);

b. facilitating dialogue;

c. facilitating critical analysis (Mason and Mitroff, 1981); and, hence

d. bringing about enhanced understanding of *systemicity* (Checkland, 1999).

1.15 Summary – Chapter 1

This chapter introduced complexity. A *Complexity Index* was defined to help us measure the complexity we face in given situations. It was explained that many everyday situations we face can be described as 'wicked', that is they are systemic, complex, and dynamic. 'Wicked' problems are confounding to diagnose and to correct, especially when they involve causal feedback mechanisms and this feedback is delayed.

Many 'wicked' problems are highly important and most worthy of solving. Unfortunately we are not well prepared to tackle them. Before we can deal with these problems we need to be equipped with a means of recognising them for what they are. This chapter introduced cognitive and concept mapping techniques. Mapping will be used throughout the dissertation as a graphic and analytical tool. Mapping helps us uncover the strongly coupled and interconnected nature of problems.

The difficulties we have in learning in complex environments was briefly discussed and the impact on us individually and our organisations was introduced. The need for a framework for participative analysis, decision-making, and strategy development was argued. Chapter 1 recognises that the notion of an *entire invariant paradigm* is severely limiting in a complex world. Once we recognise this and the complexity of the world around us, we should readily accept our human cognitive limitations in dealing with that complexity, especially when dynamic situations are involved. There can be many stakeholders and many factors interacting in ways that make management of complexity very difficult. This chapter provides a tutorial through which techniques applicable to subsequent analysis are demonstrated.

1.16 Significant Contributions Made in Chapter 1

This chapter identifies disjunction between qualitative and quantitative system dynamics methods. A number of reasons for this, were found. An argument for quantitative modelling is easily sustained when problems are 'hard' in nature. In contrast, problems containing 'soft' variables are not so easy to model. But, qualitative modelling may be the only way to address certain problems. It was suggested that populating models with estimated data sets can be problematic. This is an issue that cannot be separated from considerations of which techniques, qualitative or quantitative, might be used in a given situation. This chapter identifies that to be successful in qualitative modelling, extensive experience in formal quantitative modelling is required. Identifying such issues is a necessary pre-cursor to investigating how to integrate qualitative and quantitative techniques.

CHAPTER 2: CHOICE AND DECISION-MAKING: DEALING WITH DYNAMIC COMPLEXITY

Synopsis

In this Chapter an argument is developed that the way we most frequently decide, *naturalistic decision-making*, and our human cognitive limitations can contribute in both productive and counter-productive ways to our perceptions and attempts to manage ‘wicked’ problems. How this might affect the design of problem-solving methods and our approach to decision-support is considered.

This Chapter addresses managerial cognition, choice, and decision-making in the context of ‘wicked’ problems. It looks at human cognition, cognitive limitations and failures, and organisational and cultural impacts on choice and decision-making, as they affect design of interventions intended to address complex, dynamic, systemic problems.

It looks at recent research into choice and decision-making. This information is used to guide development of decision-support systems and the design of strategy development activities in organisations.

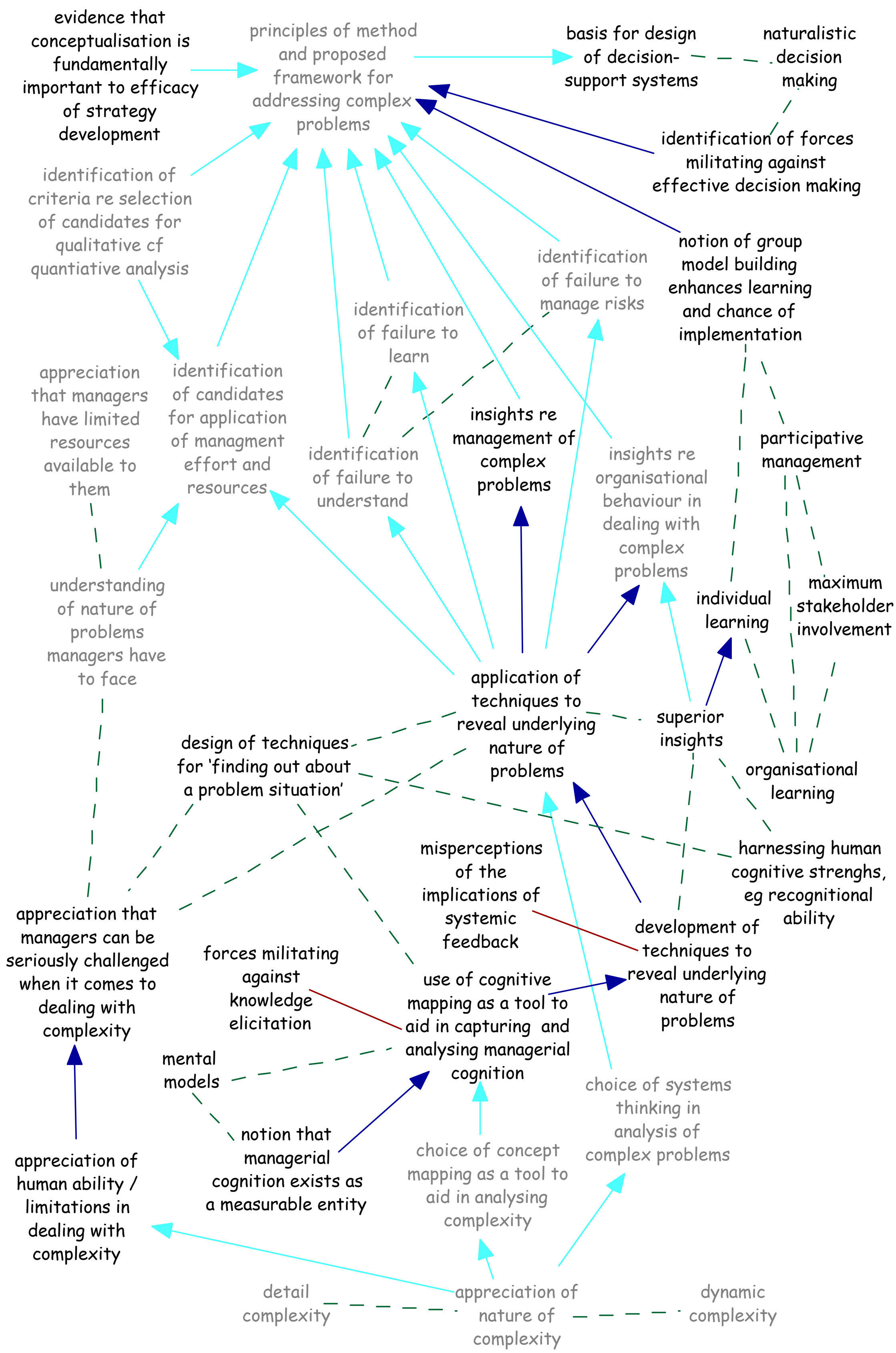


Figure 2-1. Concept Map - Synopsis Chapter 2 (1)

Note:

1. Concepts shown in black text are contained in this chapter.

2.1 Fundamental Importance of the Conception Phase

As a general principle, the cost / efficiency gains in projects accruing from effective conduct of the conception phase are depicted below in Figure 2-2. This clearly suggests conceptualisation is a critically important and formative activity. The better we are at it the greater the rewards.

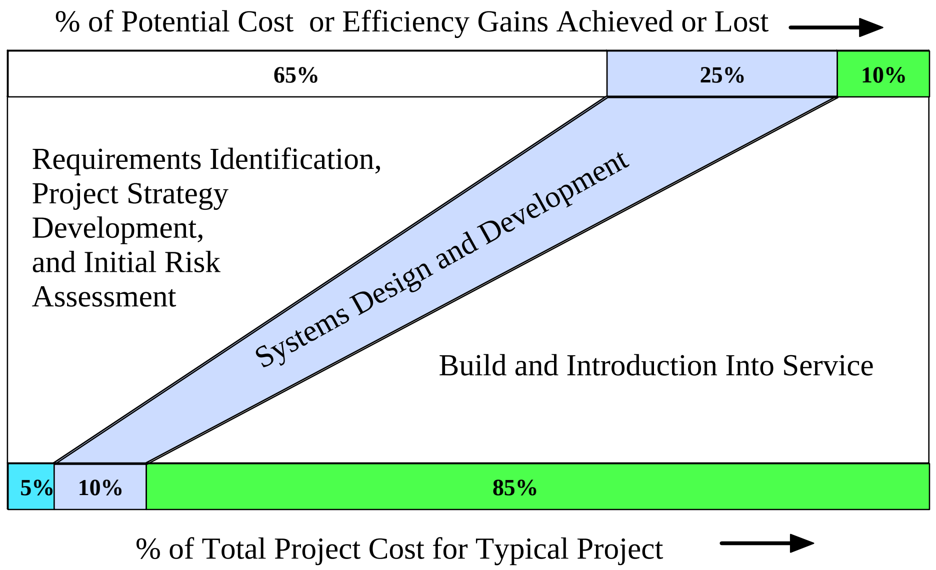


Figure 2-2. Fundamental Importance of Conception Phase / Activities (1)

Note:

1. Derived from Australian Joint Parliamentary Committee on Public Accounts, Report 243, 1986, which analysed effectiveness of systems engineering and materiel acquisition practices in the Department of Defence.

Considerable research has been conducted into the processes of selecting and applying problem solving techniques, while less emphasis has been placed on the formative stages of decision-making (Leavitt, 1976: 5-12; Mintzberg, Raisinghani, and Thoret, 1976: 246-275). Several researchers suggest that great benefit might be derived from applying our efforts to finding ways to harness extant or emerging analytical methods and building them to provide powerful decision-support tools and techniques (Lane, 1993, Nutt, 1989; Rosenhead, 1989; *System Dynamics Review*, 1994).

2.2 Maximum Stakeholder Involvement – An Important Principle

Around fifty years ago, organisational change management pioneer Kurt Lewin was successfully employing organisational change techniques that include what we now accept as action research. Lewin's legacy to management, the 'learning organisation' is variously described in the modern systems thinking literature, with virtually no acknowledgment of Lewin's pioneering contribution. The logical extension of participative management and group decision-making in dynamic, systemic problem settings is the group model building technique developed by Vennix, where:

> … the primary goal is not to build *the* model of *the* system, but rather to get a group engaged in building a… model of a problem in order to see to what extent the process might be helpful to increase problem understanding and to devise courses of action to which team members will feel committed (Vennix, 1996: 3).

Not all stakeholders are willing participants in action research. Unwilling or obstructionist stakeholders are referred to as *gatekeepers*. Vennix (1996), Andersen and Richardson (1997), and Eden and Ackermann (1998a) acknowledge the potentially debilitating impact that gatekeepers can have. Like Lewin, they agree that these key stakeholders must be involved from the earliest time and to the fullest extent:

> One striking effect of Lewin's gatekeeper theory… [now more than fifty years] later is that he always had the emphasis right in deciding who to include – those who *directly controlled* the situation… If you want any change to succeed, get the gatekeepers in on it early. The field is strewn with skeletons of… change programs that used all the right… techniques but had the politics of involvement wrong. It is a mistake to charge ahead with a project just because some manager blesses it from Mount Olympus. Gatekeepers are found in all functions and at all levels. Getting them on board is a principle, not a technique. How to do it in *this* situation is exactly the action-research problem (Weisbord, 1987: 88-91).

To have key stakeholders as fully involved as their busy schedules permit is not enough; we need to understand them and how they think. This is vitally important if we are to provide support to strategy development, or design and build decision support systems that stakeholders, particularly executive decision-makers, will trust and use (McLucas and Linard, 2000). This is discussed further in the context of the Defence Preparedness Resource Modelling (DPRM) case application at Chapter 10.

2.3 Need to Understand Managerial Cognition before Building Decision Support Systems

Effective decision support is needed to help decision-makers deal with the massive complexity described at 1.4. Before we can build truly effective decision support systems we need to understand the problems, and we also need to have a comprehensive understanding of the way managers see those problems. We need to understand managerial cognition, how we might strengthen it and, ultimately, how best to exploit it. We need to be able to relate to managers through being able to relate to the ways they think. We need to be able to elicit and analyse what they say they think with the aim of gaining insights into how they really think. Specifically, we need to:

a. know the differences between ‘espoused theories’ and ‘theories-in-use’ (Argyris, 1992; 1993; 1994);

b. be able to identify the nature and limits to managerial ‘domains of action’ (Laukkanen, 1998: 171);

c. understand the influence that individual managers have as ‘gatekeepers’ on access, provision, and interpretation of information;

d. understand impediments to both individual and organisational learning created by the ways people think;

e. develop skills in eliciting, reading and analysing constituent elements and structure of managerial cognition; that which Laukkanen (1998) calls ‘cognitive content’;

f. develop skills in analysing and comparing specific cognitive content, views, perspectives, underlying assumptions, or hidden agenda of those involved in decision-making;

g. understand which tools and techniques are effective for analysing and comparing cognitive content; and

h. overall, appreciate what might be done to improve managerial cognition, that is, to enable revision and validation of mental models, and to support decision-making.

Figure 2-3 depicts relationships between elements comprising managerial cognition.

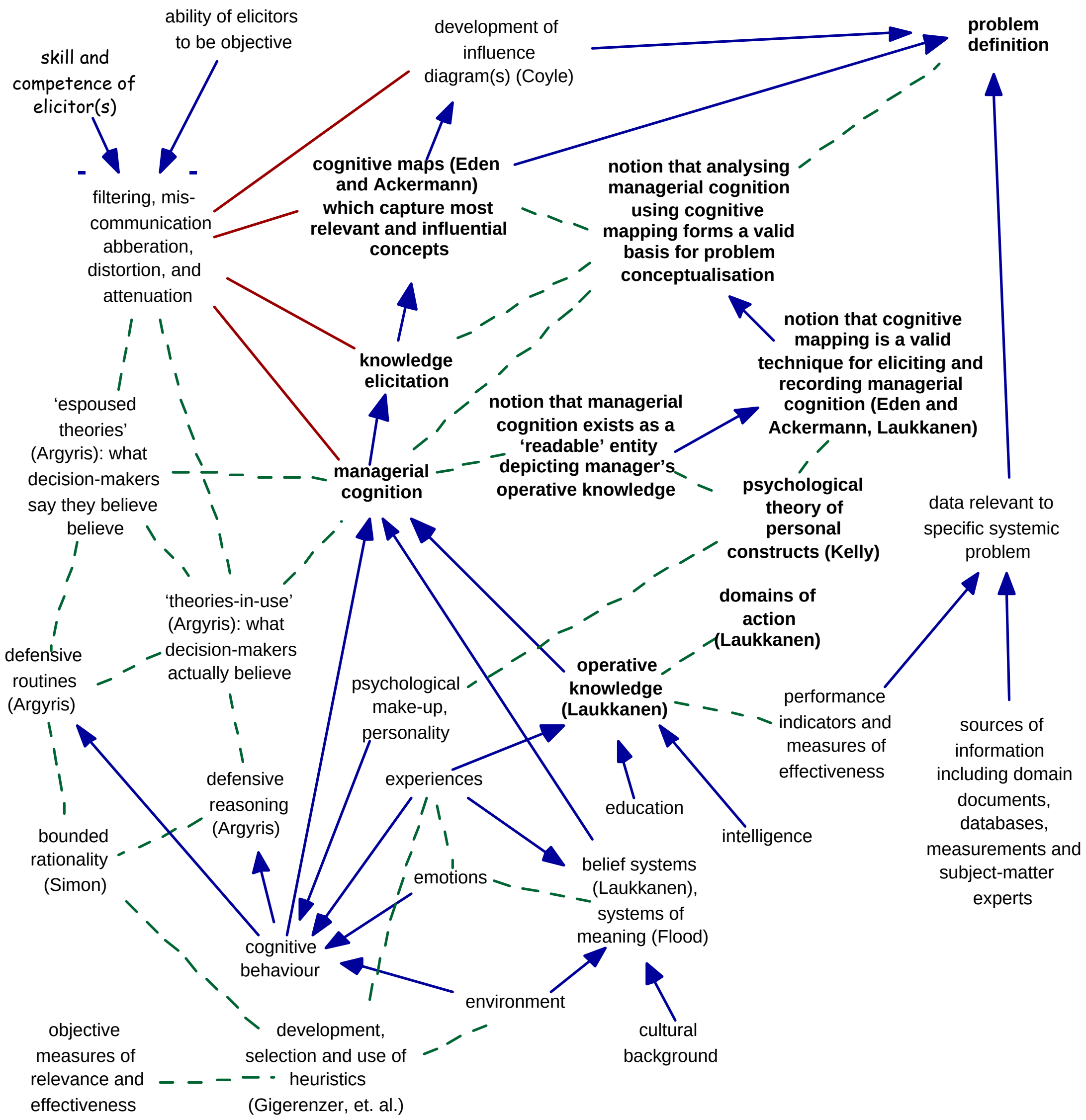


Figure 2-3. Managerial Cognition (1)(2)(3)

<u>Notes:</u>

1. Arrows depict causality in a fuzzy logic sense. Dashed lines depict connotative relationships. Solid lines without arrowheads depict conflict, or potential conflict, between concepts.
2. Linked concepts in plain text suggest there are many things to take into account in reaching sound problem definition.
3. Whilst this diagram is strictly as the author's interpretation, it is considered generally applicable to knowledge elicitation and problem conceptualisation.

2.4 Knowledge Elicitation Based on Managerial Cognition

Vennix (1996) reminds us that when it comes to 'wicked' problems there can be dispute among stakeholders about whether or not problems exist, and if there are problems what is the exact nature of those problems. A growing number of researchers and practitioners are using various forms of mapping including cognitive or concept mapping to uncover the nature of a perceived or real problem situation, and to aid in problem conceptualisation, or problem definition. Eden and Spender (1998), describe managerial cognition in the context of problem-solving and learning. They explain strengths, weaknesses and limits of methods used to elicit and analyse managerial cognition.

At this point it is necessary to make the distinction between individuals and organisations. Individuals possess cognition, but organisations do not. Individuals learn. The form of learning that occurs in organisations does not come about through the development of a single system of meaning or, in relation to any particular issue, through development of comprehensive and unanimously understood schemata. Arguably, a learning organisation exists when there is a shared reality. At best, this is the close alignment of a number of individual mental models.

Attempting to combine the cognitive maps of individuals off-line, that is without the intimate involvement of the individuals, who go through a process of negotiating and creating a shared reality, is problematic:

> Cognition belongs to individuals, not to organisations; the attribution of cognition to an organisation is problematic and depends completely upon the legitimacy of reification. Even if reification can be justified on the practical grounds that doing so allows the research question to be addressed, the source of data are dependent upon eliciting material from individuals, or small groups, or from documents written by individuals or a team… [For example,] what is written in documents is mediated by considerations of formality, audience and record keeping. The issue of reification is further exacerbated once the relationship between emotion and cognition is recognised; emotion can only belong to an individual (Eden and Ackermann, 1998: 193).

The basic argument for use of this type of mapping is that operative knowledge, that is, manager’s knowledge relevant to the problem at hand, exists as part of managerial cognition and this can be elicited, mapped and used to inform problem conceptualisation. This is depicted in Figure 2-3, above, as concepts in bold. Fundamental to mapping managerial cognition are the following notions:

a. Managerial cognition exists as a ‘readable’ entity depicting managers’ or decision-makers’ operative knowledge, relevant to that person’s domain of action.

b. Cognitive mapping is a valid way of eliciting and recording managerial cognition.

c. Analysing managerial cognition using cognitive mapping is a valid means of informing problem conceptualisation.

2.5 Human Decision-Making – Bounded Rationality and Heuristics in Quick Decisions

Gary Klein (1998) finds that decision-makers use naturalistic decision-making as the primary basis for their decisions, and this is backed up by mental simulation to imagine how strategies resulting from their choices might be played out. Klein’s observations come from many years of research, much of which has been undertaken with the support of the US Army in the context of decision-making under pressure of time and when information is limited. It is somewhat disturbing, as Klein (1998) argues, that the decision strategies most frequently used for decisions under pressure of time, or in the absence of information, are also used by decision-makers when facing complex dynamic problems. New evidence coming to hand, such as that recently published by Gigerenzer supports Klein’s view that naturalistic decision-making is also frequently used to make strategy choices. The risk in applying naturalistic decision-making in complex, dynamic situations is that the insidious aspects of dynamic complexity can stack up unfavourably against it. Gigerenzer *et al.* (1999)investigated how we use the short-cuts in our ‘adaptive toolbox’ in everyday situations was put to a series of tests:

> In the real world, a good decision is less about finding the best alternative than finding one that works. Herbert Simon of Carnegie Mellon University in Pittsburgh was one of the first to recognise this in the 1950s when he coined the term “bounded rationality”. He pointed out that the way any animal thinks depends on its cognitive limitations and the environment in which it lives. … Simon’s ideas have become fashionable in recent years, and the Berlin researchers are leading the renaissance.

> They point out that our minds like our bodies have been shaped by evolution: we have inherited ways of thinking from those of our ancestors whose mental tools were best adapted for survival and reproduction.
>
> No time then for careful calculations – a cogitating ancestor would have risked losing dinner, a mate or even his life. Instead, our mental tools are fast and frugal. They allow us to make decisions based on very little information and using simple rules. Each tool, or heuristic, is designed to resolve a certain type of dilemma under certain circumstances… Although they apply to different sorts of problems, heuristics have a common structure, which arises from the way humans make decisions. First, we search the environment for information, or cues, upon which to base a choice. A heuristic contains rules that direct the search. Next, we must stop searching. It's pointless trying to find out everything there is to know about a nut or berry if we starve in the process. Heuristics contain a stopping rule, often ending the search after only a few cues have been considered. Finally, we must make a choice – eat, run, mate, attack (New Scientist, 1999: 30-35).

The heuristics identified by Gigerenzer's research team include (work on heuristics and biases by Kahnman and Tversky and others is acknowledged, noting that the purpose here is to illustrate relevance rather than to review the body of knowledge):

a. *Recognition Heuristic.* This involves choosing 'the familiar' as the only cue worth considering. In many situations, simply choosing what you recognise will work better than choosing at random. It was found that knowing more, or having additional information made available, was not helpful when the *Recognition Heuristic* was invoked.

b. *Minimalist Heuristic.* This involves searching through a sequence of cues until one is found which distinguishes between alternative courses of action. *Minimalist Heuristic* is perhaps the natural progression from the *Recognition Heuristic.*

c. *Take the Best Heuristic.* This heuristic uses the cues in order of importance, stopping the search as soon as one cue distinguishes between the possible choices.

d. *Categorisation by Elimination Heuristic*. This uses a succession of cues to whittle away the alternatives until only one remains.

e. *Satisficing Heuristic*. This involves stopping and making a choice when what Simon calls 'satisficing' occurs. In these situations we set ourselves aspiration levels – which may alter over time – and stop looking only once these have been achieved.

Whilst the use of heuristics does not always produce the best results, the research team found that:

a. heuristics work surprisingly well in a broad range of situations;

b. not only do they allow us to choose between alternative courses of action, they also work when choice doesn't come with all the options up front, in which case it becomes necessary to search for all the options as well as the cues with which to distinguish between them;

c. people tend to use more calculated reasoning when they can take their time; and

d. heuristics come into their own when people are forced to think on their feet.

The line between deliberate decisions, involving careful consideration, and those involving judgement and intuition, where heuristics are invoked, can be blurred.

2.6 'Gut Feeling' in Human Decision-Making

Heuristics are fundamental to our decision-making, so much so that their use leads to decisions on the basis of 'gut feeling' (intuition) which describes those situations where heuristics are invoked and the choice ultimately made cannot be fully explained by the person taking the choice, or making the decision. In September, 2000, Vice Chief of the Australian Defence Force (VCDF), Lieutenant General Des Mueller, was being briefed by a colleague, another PhD candidate, on the use of a particular decision support tool. At the end of the briefing the VCDF responded by stating that ultimately all decisions are made on the basis of intuition and judgement.

At about the same time, Major General (retired) Duncan Francis, was interviewed. In relation to decision-making, he commented '… decision-making is like building bridges [and we have been building bridges for thousands of years]… if they look right, they probably are.'

2.7 Human Decision-Making – When We Get It Wrong

Klein (1998) argues that heuristics, particularly the recognition heuristic, bounded rationality, and mental simulation of selected strategy, or strategies, play critical roles in decision-making. Klein argues that whilst heuristics are generally associated with decision-making under pressure of time, they are used in deliberate decision-making much more frequently than many decision-makers would admit.

Gigerenzer et. al. (1999) join Klein in suggesting that the use of heuristics is not confined to situations where time and information are limited. Indeed, it seems there is surprisingly little use of detailed analysis and comparison of alternative strategies, despite the institutionalised teaching of these approaches. Analysis of options by consideration and weighting of all relevant factors is known as Franklin's Rule (Gigerenzer et. al., 1999: 26-7). In many situations involving recognition, heuristics such as *Minimalist*, *Take The Best*, and *Take The Last* outperformed *Franklin's Rule*, and performed as well as *multiple linear regression* (Gigerenzer et. al., 1998: 87-91).

Despite the apparent strengths and utility of heuristics, there are risks to decision-making in complex environments that come from using heuristics, judgement and intuition, or gut feeling. To make this point to students I often tell the following story:

> An engineer friend who maintained the old car his wife drove tried to explain that it was likely to stall on a hot day when the engine temperature rose and the fuel in the carburettor vaporised. In some old cars this particular problem was exacerbated by an inefficient cooling system. His wife developed her own way of dealing with the overheating and stalling problems. On every occasion when the car hesitated and the temperature gauge indicated rising temperature, she stopped, raised the bonnet and allowed the engine to cool. When the radiator had cooled sufficiently to permit safe removal of the radiator cap, she filled the radiator from the ample supply of water she always carried.
>
> She looked for the familiar cues – a warm day – hesitation or frequent misses in the engine – increasing engine temperature – steam coming from the engine or the smell of oil from the over-hot engine. This was treated in the same way – stopping when it was safe to do so, raising the bonnet, and etc. This worked every time – well almost. The last time it happened, except that it was a cool day, the other cues presented and the normal remedial actions were taken. However, they proved totally ineffective. The radiator was refilled, but the engine could not be restarted. It could not even be

cranked over by the starter motor. It had seized from lack of oil. Indeed, my friend's wife claimed that she was totally reliant upon him to check the oil level. So she never had a need to check it.

On every occasion, her search for cues ceased when she had filled the radiator. In retrospect, the heuristics she called upon under these circumstances should have included consideration of an additional cue, the presence of sufficient engine oil. In this case:

- the mental models my friend's wife had of the workings of the engine were incomplete,
- the set of heuristics invoked was not appropriate to all circumstances she might encounter, and
- satisficing ceased too early for the given problem situation.

A mechanically inclined person would have noted the absence of reference in this story to the oil pressure warning lamp, which lights when oil pressure is low. This lamp was operational, but its intermittent flashing was ignored. Weeks beforehand the alternator lamp had behaved in a similar way, but the alternator had since been overhauled. This time, an intermittently flashing lamp was registering low oil pressure. It was ignored in much the same way as the alternator lamp had been over previous weeks.

2.8 Cognitive Failure

In complex environments, there is always a risk that flawed mental models, or inappropriate heuristics are applied by decision-makers. Decision-makers, like all humans, can suffer from various forms of cognitive failure, failure to observe accurately and react appropriately to the world in which they are immersed. Bias is just one form of cognitive failure. Barnes (1984) studied cognitive bias in strategic planning and noted how the following were called into play:

a. *Availability*. People judge an event as likely if instances of it can be recalled easily, despite evidence of occurrences being quite rare. In a sense, we are observing here that those easy to understand things are easy to remember, and things that are easy to remember are seen as occurring frequently.

b. *Hindsight*. Knowledge of an event's occurrence increases the perception of that event's inevitability. So, we are not surprised about what happened in the past.

c. *Misunderstanding the Sampling Process*. We tend to attach too much credibility to sparse occurrences of events, and place too much reliance when building theories on too few data points.

d. *Judgements of Correlation and Causality*. Too often, we tend to attribute causes to un-correlated events.

e. *Representativeness*. This failure stems from our failure to ask the question… 'how representative is this of the underlying process?

Powell (1995) observes that there is a common overweighting of the heuristic process:

> … if it is based in experience then we believe it to be true. Direct experience is unduly weighted in decisions… [one consequence of this is that] as managers we tend to be very wary of probabilistic measures, and seek certainty from our advisors where none can exist. We distrust any opinion with an associated probability, possibly because we seek the specious certainty of expressed knowledge. The comforting illusion of control over an uncontrollable world is a powerful one (Powell, 1995: 36).

2.9 Desire to Keep it Simple

Many decision-makers ask for, indeed demand, simplicity even when it is not possible to avoid inherent complexity. Simplicity, here, would be characterised by $C < 5$, which corresponds to a simple system described by a first order differential equation, which also corresponds to the upper limit of complexity we can cope with using mental simulation. See 1.4. Further evidence of people's desire to keep it simple is Meadows' (1989) observation that many people faced with difficult problems look for 'gold nuggets' – fix the one single thing that is wrong, and fix the problem.

2.10 Human Decision-Making – Belief and Learning

Heuristics are not the only devices we call upon in our decision-making. Kline (1995) explains we have the ability to rapidly recall schemata, that is, all the ideas in a person's head which are used to represent and interact with the world. Senge (1990) calls these 'mental models' whilst Kelly (1955) calls them 'personal constructs'. Complex schemata are learned:

> Some of our human schemata are simple, some moderately complex and some relatively very complex… Complex schemata constitute the basis for a doctor in diagnosing illness, for a musician in playing his or her instrument, for an engineer designing a device, and so forth. These more complex schemata are not merely a string of information but, rather, form complex relational networks that are acquired by and only by long experience and usually focused study… all disciplinary knowledge is based on relatively complex, learned schemata… (Kline, 1995: 31-32).

In our minds, schemata are broken down into chunks. Our working memory can hold about four chunks, or about seven bits [‘bits of information’, not to be confused with digital bits], whilst our long-term memory can hold about 50,000 bits of information for a single area, and around 100,000 bits in total. These can be rapidly recalled using the brain’s multiple, parallel processing capability. Dennett (1991) hypothesises that parallel processors throw up multiple drafts – that is, possible solutions from our long-term memory – and working memory chooses which one to follow. Gigerenzer’s work suggests that our heuristics are called upon to aid that choice. Dennett explains that the processes of our working memory are serial and relatively slow compared to the recall from our long-term memory:

> Miller’s 7-Bit-Rule [(Miller, 1956) relating to the number of bits we can hold in our working memory] has been checked and rechecked by many researchers in many areas of mental activity. It is established empirically beyond reasonable doubt. The “7-bit-limitation” on the human working memory, imposed by Miller’s 7-Bit-Rule, is probably the most important single constraint on the human mind regarding how we form sysreps… Sysreps are truth assertions we hold and recall when we want to discuss, analyse, think about or write about the following:
>
> - a picture,
> - an equation,
> - a mental image,
> - a conceptual model,
> - a word description, and etc. (Kline, 1995: 16-46).

The relationship between working and long-term memory and schemata may be as depicted by Figure 2-4.

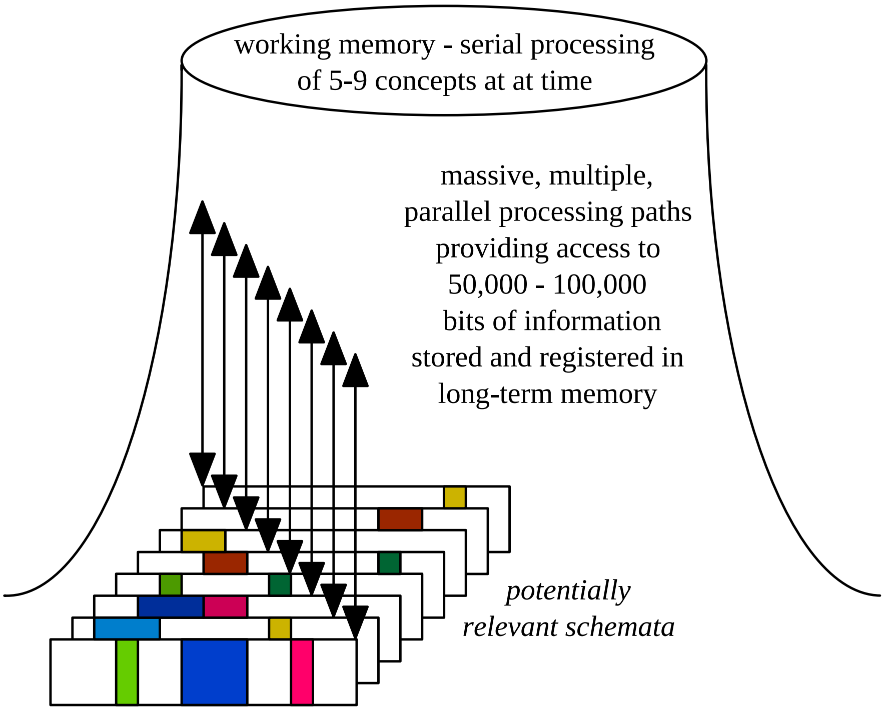


Figure 2-4. Relationship between Memory and Schemata

This has important ramifications for the way we go about solving problems. Sysreps, schemata, mental models, or personal constructs are only really valuable as bases for understanding and learning if they have been developed from valid and relevant experiences. Situational awareness and option choice are more involved in complex problem solving, so we need more deliberative and more publicly defensible decision-making.

2.11 Dynamic Environments – Misperceptions of the Implications of Feedback

Klein (1998) suggests decision-makers firstly invoke recognition to determine a problem is typical of something seen before, then, through combination of schemata recalled from long-term memory and cues from the current situation, build mental simulations of strategies. Even though this is the primary means of making decisions under constrained time and when there is limited information, a growing number of researchers argue such methods are also used frequently for decisions where no such constraints apply. This can be problematic in dynamic situations, especially where cause and effect are not proximate, either temporally or spatially. Such is the case where feedback mechanisms exist. Add the complication of dynamic feedback mechanisms, and we are in danger of getting it quite wrong, failing to predict systemic behaviour. Kleinmuntz (1993) warns that much of the research in the field of behavioural decision-making has been undertaken in situations suffering one unfortunate limitation…

> The tasks studied are almost exclusively static, discrete instances of judgement or choice. Decision researchers have overlooked the complex, time-dependent nature of many real decision environments, particularly the feedback structure linking previous decisions to changes in the decision environment (Hogarth, 1981)… Recently, [Broadbent and Aston, 1978; Dörner, 1980; Mackinnon and Wearing, 1985]… studies have begun to examine how this source of feedback influences the effectiveness of decision rules in dynamic tasks… a pattern seems to be emerging: Decision makers have exhibited systematic patterns of poor performance that suggest that they are insensitive to the implications of feedback in these dynamic environments (Kleinmuntz, 1993: 223).

In an attempt to answer questions regarding the types of decision support we might provide, it is necessary to look at the most problematic aspects of decision-making in dynamic environments. Of particular interest are misperceptions that are associated with feedback, regardless of decision-making being deliberate or intuitive.

The important implication is not so much that decision makers fail to see the relevant information and fail to develop 'situation awareness' (Klein, 1998: 33)…

> … situation awareness can be formed rapidly, through intuitive matching of features [either in the actual environment or a model of it], or through mental simulation. Sometimes a situation reminds us of a previous event, and we try to use analogy to make sense of what is happening. At times there are several competing explanations and we may have to compare them. Usually we will scan each explanation to see if there are elements that do not seem plausible, so we can reject the less likely ones and keep the best (Klein, 1998: 90)…

But, they are likely to fail to see the ramifications of feedback mechanisms for decision-making.

2.12 Relationship Between Metacognition and Design of Decision Support Systems

We need to be able to determine when the type of intuitive thinking described may be appropriate and when it is not. Klein defines being aware of how we are thinking as metacognition (Klein, 1998: 158). Both we, and those facing 'wicked' problems, need metacognitive skills. In research or consultancy situations, we need ways of eliciting, surfacing, and testing how individuals actually think. We need to have effective means of determining that the way decision-makers are thinking about the problem really is appropriate. This was recognised by Mason and Mitroff (1981), and led them to develop their Strategic Assumptions Surfacing and Testing (SAST) intervention. A co-requisite, here, is a detailed appreciation of the nature of complexity.

2.13 Identifying Where 'Insights' Occur

The knowledge elicitation, assumptions surfacing and testing, modelling and critical analysis activities are about more than simply gaining 'insights' into complex problem situations. Before we can build effective decision-support systems, we must understand how decision-makers think. Coyle (2000) recognises this, although he states it in a somewhat different way, suggesting there is a need for research into understanding and insight that come from qualitative compared to quantitative modelling:

> … it will be necessary to have some sort of definition of 'understanding' to take us away from the glib repetition of 'insight'. In particular, it seems likely that it will be necessary to be clear about ***where*** the insight lies (Coyle, 2000: 241) *(emphasis added).*

Also highly relevant to 'insight' building are those activities that create the context in which systemic structures, feedback, delay, non-linearity and changing loop dominance can be recognised, noting recognition is an essential precursor to analysis. Further, there appears to be a need for a 'rapid prototyping' tool that supports problem conceptualisation through analysis of systemic causality. Such a tool is described later in this Thesis. No such tool is known to exist despite inferences in the literature of the need for it. This tool also overcomes the difficulty of 'double counting' the contributions of causality in influence diagrams, a problem identified by Coyle (2000).

2.14 Human Decision-Making – Different Perspectives on The Same Problem

Stakeholders <u>all</u> have different perspectives on any given situation – one will view a glass of water as half full, whilst another will view it as half empty. Kosko (1993) observes that this demands a different way of viewing problems, a way that accommodates 'fuzzy logic', where there are many shades of grey.

The need to accommodate perspectives of stakeholders was recognised by Vickers (1970). Klein (1998) suggests each stakeholder relates to a different set of cues and builds on his or her own situation awareness, or perspective. Checkland's Soft Systems Methodology (SSM), for example, acknowledges the importance of stakeholder perspectives and the contribution to richness in problem conceptualisation made through accommodating varying perspectives. What SSM takes into account in helping stakeholders find out about a problem situation, rather than how SSM is applied, is described at 2.28.

2.15 Masking the Reasoning Behind Decisions – *Ratio Decidendi* and *Obiter Dictum*

In law, for example, the actual basis upon which a judge formulates a specific decision is infrequently spelt out. Instead, the laws and precedents upon which a judgement is ostensibly based are enunciated. This leaves students of law and the legal fraternity, more broadly, often wondering… 'what was the judge really thinking?' The difference between *ratio decidendi* and *obiter dictum* is explained as follows:

> A judge will often find it necessary or convenient to state principles of law which relate to hypothetical events rather than to specify facts of the case. Such statements sometimes serve to illustrate or clarify the principle which is actually applied in the case (the *ratio*) but they are not themselves *rationes*. Any such statement of a rule of law is called an *obiter dictum*… The distinction between *ratio* and *obiter*, therefore, can be stated thus: pronouncements of legal principle necessary for the judge's decision on the established facts of the case are the *ratio* or *rationes decidendi* of the case, whereas the pronouncements of legal principle which are not strictly relevant to the issue or issues will be *obiter dicta* only.
>
> It must be appreciated, however, that not every statement of a rule of law by a judge is necessarily *ratio* or *obiter*. Frequently, during the course of the judgement, the judge will restate and discuss *rationes* from existing cases. That is simply a recitation of the development of the relevant legal principles – a foundation of the judge's reasoning – but those statements are neither *ratio* nor *obiter* in the case before the court (Morris, Cook, Creyke and Geddes, 1992: 40).

By comparison with deliberations of the judiciary, when it comes to executive decision-making, relatively few public statements of *'obiter'* are made. Further, the *'ratio'* involved in a particular decision is revealed even less frequently. So, the real basis of decision-making invariably remains masked from the observer's view. Of course, what constitutes *'obiter'* and *'ratio'* only makes sense in the context of deliberate decisions.

Many decisions are made under time constraints or when information is incomplete. These are the most likely situations in which executive decision-makers will invoke heuristics or mental short cuts. It is the author's observation over many years that busy decision-makers who should take time for considered decisions frequently do not, instead, it seems, often relying heavily on the potentially unsubstantiated advice of others, on trust, and invoking their decision heuristics for the final choice. The observations of Barnes (1984) and Powell (1995) are also relevant here. Despite the appearance of time being taken over a decision, many highly important decisions can (apparently) be made on the basis of judgement and intuition. Klein (1998) suggests that the extra time available to decision-makers, it is spent mentally simulating events that might follow implementation of the chosen strategy and developing justification for choices already made.

When decision-makers use heuristics to resolve complex, dynamic issues the risk of error increases. That decision-makers use intuition and judgement when deliberate decision-making would be more appropriate, can be problematic. It must be emphasised that this Thesis does not set out, *per se*, to contribute new knowledge to the field of behavioural decision theory. But, design of decision support tools cannot be undertaken without an understanding of the practical implications of that theory. In practice, whether a decision is deliberate or based on intuition and judgement can be difficult to determine, just as it is difficult to obtain a judge's statement of his *ratio*. This can be problematic for designers of decision-support systems. If we do not understand how decision-makers decide in practice, it will become difficult to develop decision-support systems that executive decision-makers will trust and use. So, we are left to ponder the dilemma… 'under what circumstances do we provide qualitative, 'quick and dirty', but sufficient tools in aid of decision-makers, and when do we provide relatively sophisticated, quantitative analytical techniques intended to provide reliable and validated support to decision-makers?'

2.16 Building Understanding Relevant to the Problem at Hand

Generally speaking, we are seeking to build understanding about what underlies the behaviour of complex problems. When deciding how best to support decision-makers through design of decision-support systems, we need to determine:

a. what domain knowledge, knowledge relevant to their *domains of action* (Laukkanen, 1998), decision-makers have;

b. what relevant expertise they possess;

c. how well they appreciate the underlying dynamics; and

d. how they believe reference modes of behaviour are produced.

2.17 Systems of Meaning

Heuristics, schemata, sysreps and mental models may be the building blocks of understanding and learning, but they are only part of an individual's cognisance. An individual's cognisance fits within systems of meaning.

The relationship between cognisance and meaning is depicted diagrammatically at Figure 2-5. It is described by Flood (1999) as follows:

> Meaning arises from people's cognitive processes and the way that, for each person, their cognisance defines their relationship with other people and the world. Cognitive processes might be conceived of in terms of values, norms, ideologies, thought and emotion, coherence and contradiction. A person's actions and utterances cannot be made sense of without reference to this texture of what they think. *Values* are intrinsic desires and motivators. *Norms* underpin what is considered to be normal and acceptable behaviour. *Idealogies* are sets of ideas about how things should be. *Thought and emotion* refer to what a person thinks and how they feel about that, as well as the impact that feelings have on what a person thinks. *Coherence and contradiction* are qualities of 'validity' in cognitive processes. All of these things are key in making an adequate interpretation of what a person says and does.
>
> Cognitive processes constitute meaning that may be shared in some way between people and yet remains somehow personal to individuals. Systems of meaning that people employ may coexist and adapt in relative harmony and/or degrees of conflict. That is, systems of meaning may yield cohesion in cultural ways of living and/or tension arising from disagreement, perhaps leading to coalition building and political interaction. Appreciation of what people mean and the temperament of their coexistence are therefore of central interest when seeking 'agreement' on improvement strategies. (Flood, 1999: 110).

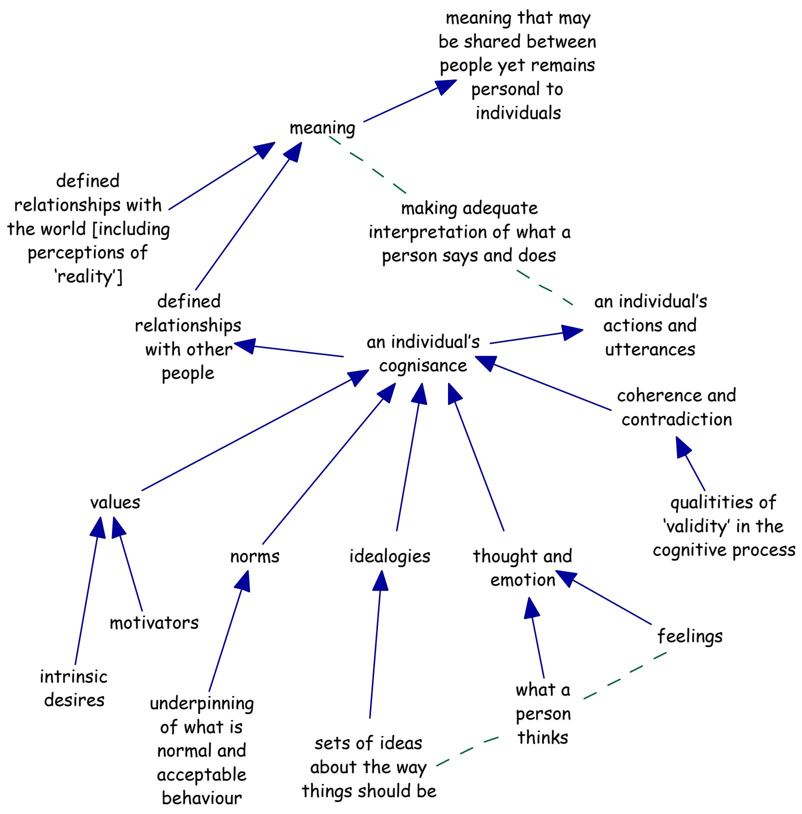


Figure 2-5. An Individual's Cognisance Within Systems of Meaning

Amongst other things, this means choices or decisions we might make cannot be divorced from feelings. Alternatively stated, there are links between cognition, emotion and cognitive behaviour: choices and decisions are rarely made on purely logical and rational bases. We need to recognise that decision-makers have feelings when we design decision-support systems for them. Further, they will only act when they feel strongly enough about a problem to do something meaningful about it (Forrester, 1985: 133-4; Checkland and Scholes, 1999).

2.18 Summary of Human Cognitive Limitations

When we do not have convenient and trusted analytical tools to help us deal with systemic behaviour, it is apparent we revert to using judgement and intuition. Judgement and intuition can be quite inappropriate in situations where complex systemic problems are involved. Noting the earlier discussion and Kline's observation that human ability to reliably solve problems is limited to those characterised by $C < 5$, Sterman makes a similar observation. See 1.4.

Kline goes on to describe the problems executive decision-makers may be called upon to solve and characterises them by $C > 10^n$ where n can range from 6 – 13 (Kline, 1995: 49-68). The gap between our cognitive capability in dealing with complexity and the complexity we face, is enormous. This, alone, suggests that using judgement and intuition in complex environments can be inappropriate, but the author's observation is that executive decision-makers frequently choose to ignore, or are unaware of, such evidence. These limitations impact on whatever methodology we might wish to design to aid our understanding of complexity. In essence:

a. The concept of feedback is generally not well understood. Feedback manifests itself almost everywhere and our ability to understand it is poor (Richardson, 1991).

b. Our decision-making is seriously challenged when it comes to complex and dynamic systems where feedback and delay mechanisms exist. Human ability to predict dynamic behaviour of complex systems involving feedback and delay mechanisms, is poor (Sterman, 1989a; 1989b).

c. Feedback dynamics easily elude human intuition and judgement (Sterman 1989c; Kleinmuntz, 1993; Diehl and Sterman, 1995: 198-215).

d. Dynamic complexity is not interpreted well by those who are responsible for managing it. Behaviour can be counter-intuitive. Consequently many strategies and policies are based on flawed or erroneous assumptions and mental models (Forrester, 1971; 1975).

e. Further to our cognitive shortcomings in dealing with complexity, we are inhibited by our inability to correctly conceptualise problems when our assumptions may be inappropriate (Meadows, 1989). Complex problems are difficult enough for us to address without being further handicapped by analysis which starts from conflicting, hidden or fallacious assumptions (Mason and Mitroff, 1981).

2.19 Harnessing Human Recognitional Capacity

Recognition is the key to harnessing human intellect in dealing with complexity. In a study of decision-making under time-pressure, Klein (1998) and his team of researchers observed and classified 156 decisions and found 127 involved 'recognitional decisions'

(Klein, 1998: 23-24). They found that when more time was available, people deliberated about options and this became a substitute for recognising a situation as ‘typical’. As a result of their decision research, Carroll and Johnson (1990) also conclude human intellect is best applied to recognition.

The mid-1980s saw the advent of accessible and powerful desktop computing which enabled rapid and meaningful analysis of dynamic modes of behaviour found in systemic problems. It is now a relatively easy system dynamics task to investigate the systemic structures that underlie these patterns of behaviour. This is achieved through capturing business rules, essentially one, or small number, at a time and ‘recognising’ they are appropriate and building them into models. As mentioned above, there is evidence to suggest that even when time is available and information is relatively complete, heuristics are invoked, recognitional decisions are made and mental simulation is used to evaluate strategies. When more time is available it is often devoted to mental simulation of strategies.

In the ‘modelling as learning’ paradigm, Morecroft and Sterman (1994), it is suggested system dynamicists are attempting to replace the process Klein describes as ‘mental simulation’ in his *Integrated Version of Recognition-Primed Decision-Model* (Klein, 1998: 17-30), with qualitative and / or quantitative system dynamics, and simulation. See Figure 2-6. Of course, we cannot hope to achieve this in quick time such as the decision-making situations Klein and his team studied.

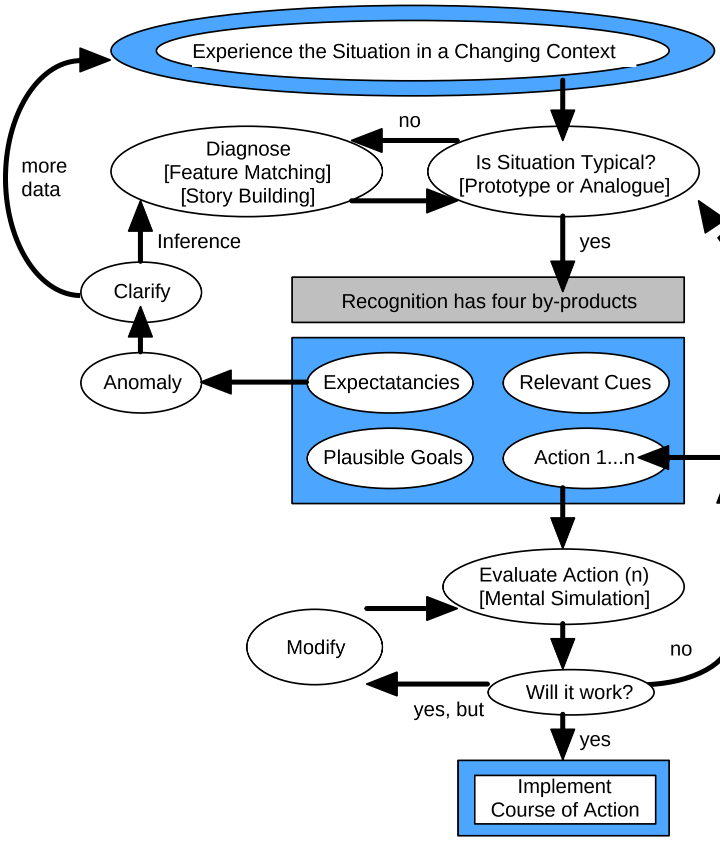


Figure 2-6. Integrated Version of Recognition-Primed Decision-Model

Here, the role of the computer is in calculation-intensive processing and graphical presentation of dynamic behaviour modes, noting that no one has yet managed to build a machine that recognizes faces as well as a 2-year-old child (Gigerenzer et al, 1999: 30). Pattern recognition to inform choice and decision-making is the domain of the human mind.

Any decision-support system we might design to help us deal with the dynamics of ‘wicked’ problems must remove the human decision-maker from the process-intensive task of calculating complex dynamics. The human decision-maker is best involved by using his or her powers of pattern recognition to spot changes in a problem’s dynamic behaviour Carrol and Johnson (1990): taking a helicopter view (Eden and Ackermann, 1998), or a world view *weltanschauung* (Checkland, 1990), rather than becoming embroiled in complicated calculations.

2.20 Importance of Communications in Decision Cycles

The interdependence of the various activities in decision-making is shown in the Decision Cycle at Figure 2-7.

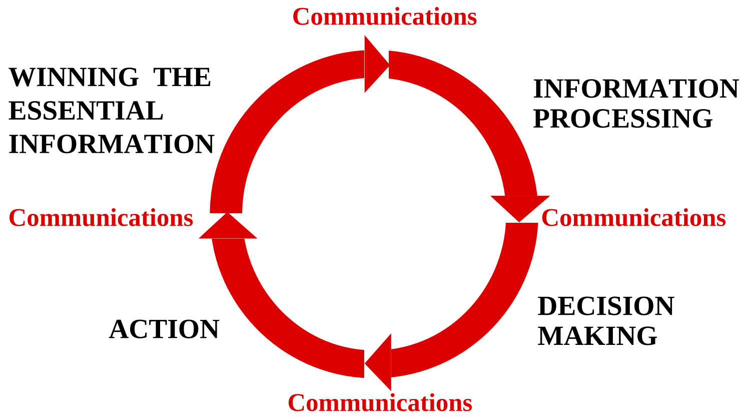


Figure 2-7. The Decision Cycle (1)(2)

Notes:

1. Originally the Boyd Cycle, after Colonel Boyd USAF, a fighter pilot in the Korean War. This is also known as the OODA Loop, involving cycles of Observing the changing situation, Orienting to what is occurring, Deciding what action to take and Acting.
2. Adapted from the Command and Control (C2) Cycle (after Ryan, 1997).

This diagram emphasises the requirement for effective communication. Mis-communication is possible at four separate points when we navigate the Decision Cycle. Mis-communication may come about for many reasons including:

a. errors in the transmission process because we are unable to express perfectly, through verbal or non-verbal communication, exactly what we are thinking;

b. errors occur in the reception process because we are unable to interpret perfectly what is transmitted, either as verbal or non-verbal communication;

c. noise levels being high relative to the signals;

d. misuse of language; or

e. confusion in the use of terminology.

Effective communication is needed during knowledge elicitation and problem conceptualisation. Equally, it is an essential part of every stage of model building, simulation, strategy development, and implementation processes. The decision cycle must be navigated many times. Facilitating effective communications at each of the points identified in the Decision Cycle is important to assuring understanding, and avoiding errors.

2.21 Dynamic and Complex Beyond Our Intuition

Flood (1999) suggests the world is whole and the whole is complex. It is increasingly complex with more and more information, intense interdependency, and relentless change. Many problems we have to face are self-organising, as discussed above, dynamic and complex beyond our intuition, and possibly our comprehension. Flood argues that the complex nature of the world in which we find ourselves is unknowable to the human mind:

> The world comprises many, many interrelationships. The dynamic is characterised by spontaneous re-organisation. Thus, it is only possible to get to grips with things that are local to us in space and time. Local in space means, 'things that we are immediately involved with'. Local in time means 'not very far into the future'. We therefore know of the unknowable, manage within the unmanageable, and organise within the unorganisable (Flood, 1999: 129).

Kline (1995) makes a similar argument. This is not meant to deny fervent attempts to address dynamic complexity, but suggests we must take considerable care in setting the boundaries of the problem space and the potential solution space. Beer (1966) cites a number of examples of poor choices in selection of problem or solution spaces. We might improve these choices through employment of scenario planning, in conjunction with modelling options, as aids to developing mental agility.

2.22 Developing Mental Agility

Developing mental agility is an important aid to learning, provided this learning is enabled through understanding of dynamic complexity. Since understanding of complex, systemic behaviour is beyond our intuition and recognition-primed decision-making, decision-making in complex, systemic dynamic environments must be supported by use of tools and techniques that expose what underlies then supports analysis of complex, systemic, dynamic behaviour.

2.23 Benefits of Scenario Planning in Building Mental Agility

The following list sets out some key aims and benefits of scenario planning, supported as necessary, by dynamic modelling:

a. People are better informed about the sorts of events that occur.

b. People are better informed about the way events may occur.

c. People are more alert about the way events occur.

d. People learn how to challenge their mental models – their mental agility is kept fit and they learn how to learn.

e. Scenario building develops means that endure, rather than ends that rarely come true. It builds new working relationships between people as well as team coherence.

f. It facilitates relevant local decision-making.

g. It can be applied to personal vision as well as to forms of agreement that underpin shared vision.

h. It provides a focus on learning about interrelatedness and spontaneous self-organisation.

i. It supports managing within the unmanageable and organising within the unorganisable.

j. It encourages learning within the unknowable.

k. It guides organisational learning and transformation, whilst recognising that this is always built on a partial and temporary view of reality (Flood, 1999: 131-2):

2.24 A Fundamental Proposition – Superior Insights Lead to Superior Learning

A recurring theme, stressed by Morecroft and Sterman (1994), Sterman (1994: 2000), and Vennix (1996), is that learning at individual and organisational levels, is critically important if we are to deal successfully with ‘wicked’ problems. A fundamental proposition here is that superior insights lead to superior learning. This learning stems from situational awareness which, in turn, informs cycles of revision and development of our mental models, making them more robust and valid, that is, ‘double loop’ learning from experience. Invoking these mental models, appropriately supported by analytical tools and data should lead to development of more effective policies, strategies, and decisions, and ongoing valid experiential learning. Organisational learning comes about through action research and action learning, and only after individual learning is enabled. The aim should be to develop mental agility with respect to what the future may bring, given the context of a complex dynamic world as described by Flood (1999) and described at Chapters 3 and 4. Unfortunately, there can be many barriers to developing mental agility.

2.25 Barriers to Learning and Effective Decision-Making in Dynamically Complex Environments

Barriers to learning and effective decision-making arise through various mechanisms. Un-referenced observations contained here are the author's interpretation of information from two sources:

a. Australian Department of Defence documents reviewed by the author during his compilation of 'lessons' from strategic planning activities associated with the 1999-2000 deployment of peace-keeping forces in East Timor.

b. A Congressional Report by US Department of Defense regarding operations in Kosovo in the late 1990s.

Whilst parts of these documents were nationally classified, only UNCLASSIFIED information is included here.

Barriers to learning and effective decision-making include the following:

a. Argyris (1994) suggests that many 'successful' senior executives have surprisingly poorly developed decision-making skills. Sequences of quite rapid promotion distance them from the legacies of their earlier decisions, so they are not forced to critically analyse their own decision-making failures.

b. All decision-makers have limited ability to deal with complexity, particularly dynamic complexity where feedback and delay occur (Sterman, 1989a; 1989b; 1989c.). This is exacerbated by a disjoint between strategic decision-makers, who often choose to distance themselves from high levels of complexity, and lower decision-making levels where managers often have to confront massive complexity. Contributing factors are:

(1) Socio-technical organisations are massively complex (Kline, 1995).

(2) Executive decision-makers, who are generally amongst the busiest in the organisation, would prefer to avoid the impositions on their time, and the extensive delays that often accompany the application of analytical techniques: for them, the true nature of complexity remains undiscovered. When this understanding is absent or deficient, over-simplification can result. This leads to the practice of seeking a single ‘golden nugget’. As Meadows (1989) suggests that this is probably the most widespread problematic assumption in the current industrial paradigm: one cause produces one effect, find the cause and fix the problem.

(3) Decision support is often untimely. It simply does not fit within the Decision Cycle, the decision-maker’s OODA Loop, as described at Figure 2-7. Critical to successful decision making is being aware of and understanding what is really happening. Winning the essential information takes time and effort, as does information processing. Unfortunately, decision-support systems are often circumvented and decision-makers rely on their own sources of intelligence and advisers.

(4) Executive decision-makers who are often intimidated by the complicated appearance of analytical methods fail to appreciate their value, mistrust them along with the ‘witch doctors’ in the organisation who advocate their use (Nutt, 1989: 32-33). Powerful and accessible analytical tools are of no value if they are untrusted. Nutt claims after more than 20 years of studying decision-making, he has substantive evidence that executive decision-makers actually mistrust analytical methods. Many would prefer to, and do, dismiss them. They see them as threatening or time wasting. Whilst executive decision-makers rarely, if ever, admit to this belief, both Nutt (1989) and Flood (1999) suggest we need to be careful when using any approach which might threaten the balance among those who have knowledge and hold power.

(5) There is a strong aversion by decision-makers to have their deeply ingrained assumptions, their mental models (Senge, 1990), psychological constructs (Kelly, 1956), schemata and sysreps (Kline, 1995: 31), 'systems of meaning' (Flood, 1999: 110-115) surfaced and critically analysed (Mason and Mitroff, 1981). Assumptions and mental models are likely to be incomplete, flawed or immature in their development, when compared with the detail and dynamic complexity needing to be managed. Kline (1995) explains that …

> … 'precise representations of systems (sysreps) used for analysis arise only in human brains, as far as we know. These transformations of information into sysreps, and the recordation of the sysreps, carry with them the possibility for many kinds of imperfectly mirroring the systems concerned, including outright errors. This is the reason why such close attention needs to be paid to how we form sysreps, how we use them and how they are influenced by the limitations of the human mind.' (Kline, 1995: 55).

Further, aversion is likely to be increased when a decision-maker's knowledge-power base is threatened. See 'Systems of Knowledge-Power' at 2.26.

(6) Strategic decision-makers are also political players frequently more concerned about the impact particular decisions have on their careers in the short-term rather than seeking out underlying systemic structures and root causes, and using that knowledge to inform their decisions, strategies and policies.

(7) The structure of many large organisations and the nature of their business activities have the natural effect of shifting the management of complexity to lower organisational levels.

(8) Information can be compartmentalised within organisations. Compartments can be sealed by organisational hierarchies and politics. As a consequence, compartmentalisation militates against the best intentions of the designers of information systems and decision support systems alike.

(9) Knowledge markets exist and market forces dictate the extent to which knowledge is traded. Davenport and Prusak (1998) explain 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 … people rarely give away valuable possessions (including knowledge) without expecting something in return.’ (Davenport and Prusak, 1988: 26).

(10) The ‘need to know’ principle also militates against sharing information. This is particularly so in Government Departments and public-sector organisations, though not exclusive to them. Decision-makers who are not granted the need to know are not only denied information but are denied opportunities to be involved in strategy development, except in a controlled and limited sense.

(11) Reward systems in organisations, particularly public sector ones, are rarely centred on rewarding the sharing of information for long-term gains, rather they reward performance measured against short-term, political or profit-centric goals.

2.26 Systems of Knowledge-Power

In all organisations, systems of knowledge-power operate. Flood (1999) describes knowledge-power:

> … the idea that people in positions of power determine what is considered to be valid knowledge and consequently valid action. ‘Systems of knowledge - power’, in which executive decision-makers are central players, militate against the sharing and flow of information (Flood, 1999: 116-122).

How systems of knowledge-power operate in organisations is depicted diagrammatically at Figure 2-8.

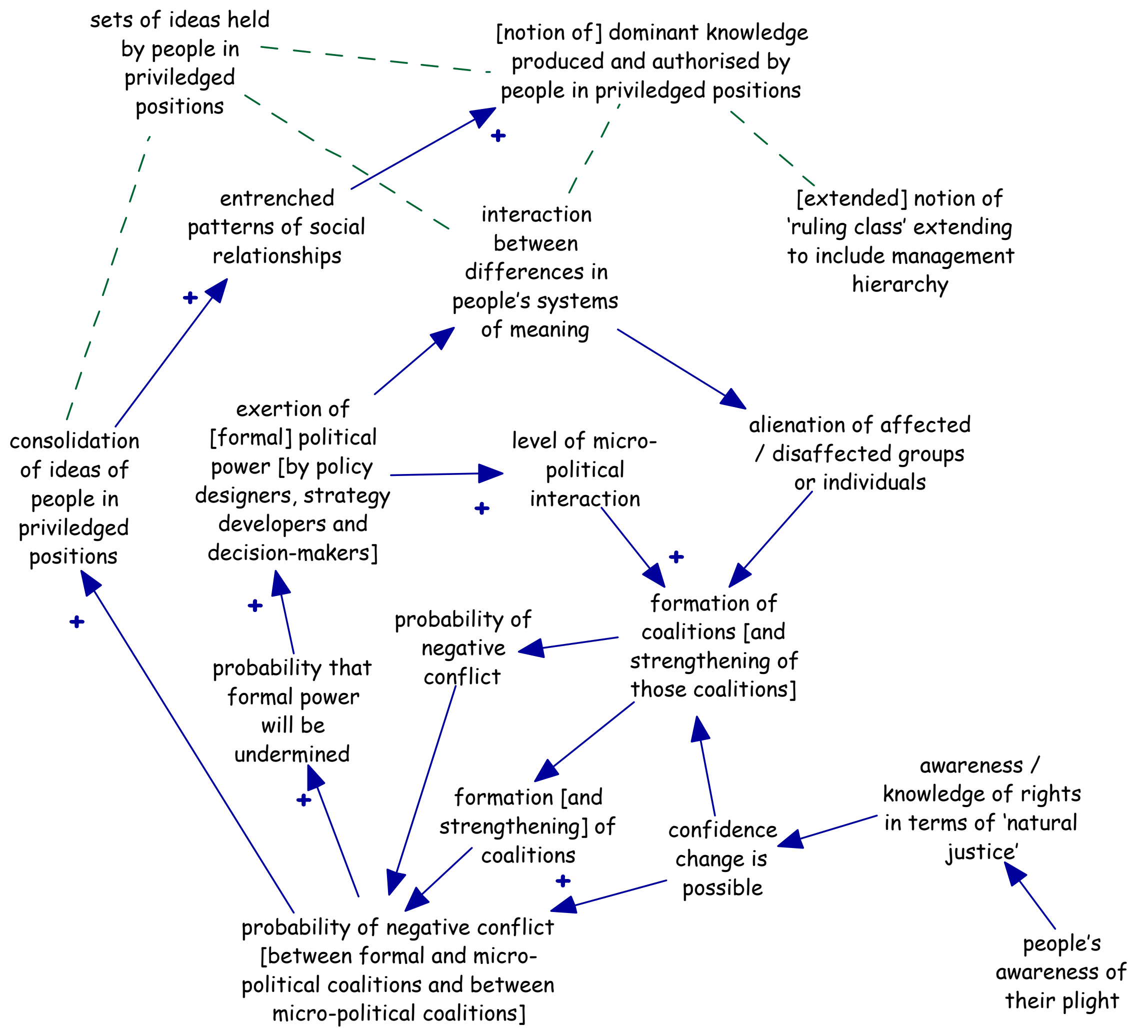


Figure 2-8. Concept Map – Systems of Knowledge-Power (1)

<u>Note:</u>

1. Concept map was derived from textual description by Flood, 1999: 116-7.

2.27 Conflict Between Knowledge-Power and Learning

In relation to shared reality in organisations, Espejo (1994) observes that:

> Organisations are the outcome of ongoing processes in which people negotiate with each other – not necessarily with the same negotiating power – their organisational constructs and thereby constitute their organisations. Indeed, participants generate distinctions of their own, which they use to coordinate their actions, and through recurrent coordination of actions (i.e., language) they create a consensual domain of action, or shared reality … (Espejo, 1994: 204).

Systems of knowledge-power militate against development of shared reality because less powerful stakeholders are told what they must believe, or are constrained in their thinking. Failure to acknowledge the pervasive nature of systems of knowledge-power when designing decision-support systems can be a significant threat to the systems themselves, individual and organisational learning and creation of shared reality in organisations.

2.28 Finding Out About A Problem Situation – The Soft Systems Methodology

In each of the cases described at Chapters 3 and 4, many stakeholders were aware that a problem existed, or that there was something wrong. The challenge is to find out about that problem situation. For reasons described immediately above, this can be a difficult task. The strength of Soft Systems Methodology (SSM) is that it acknowledges what Checkland calls the ‘complexity of human affairs’. How to apply SSM is described by Rosenhead (1989), Checkland (1990), Checkland and Scholes (1999); and ITSM 2000. SSM was developed by Checkland and has been in use, and continually evolving, for over 30 years. SSM exploits the following intellectual devices:

a. *Rich Pictures*. Rich pictures, are used in SSM to convey ideas, and to facilitate dialogue. SSM exploits *semiotics*, that is, the use of icons and symbols in verbal and non-verbal communications.

b. *Weltanschauung.* This German word stresses the importance of accommodating varying perspectives about a problem. Depending on the context, *weltanschauung* means:

   (1) a world, or worldly, view; or

   (2) what is within our view or perspective at a point in time (current affairs).

c. *Systemicity*. *Systemicity* describes the complex, dynamic behaviour exhibited by systems, or systems-of-systems. Checkland does not suggest we attempt to contemplate complete systems. Rather, like Flood, he suggests we acknowledge the complexity of the world and that the world is whole. So, the notion of *weltanschauung* is complementary to *systemicity*.

Figure 2-9, is a concept map which depicts diagrammatically what an effective conceptualisation methodology contains. This depiction serves to identify the elements of the methodology, and to highlight the elements. Similar elements can be found in other successful methodologies we might use when investigating a problem situation.

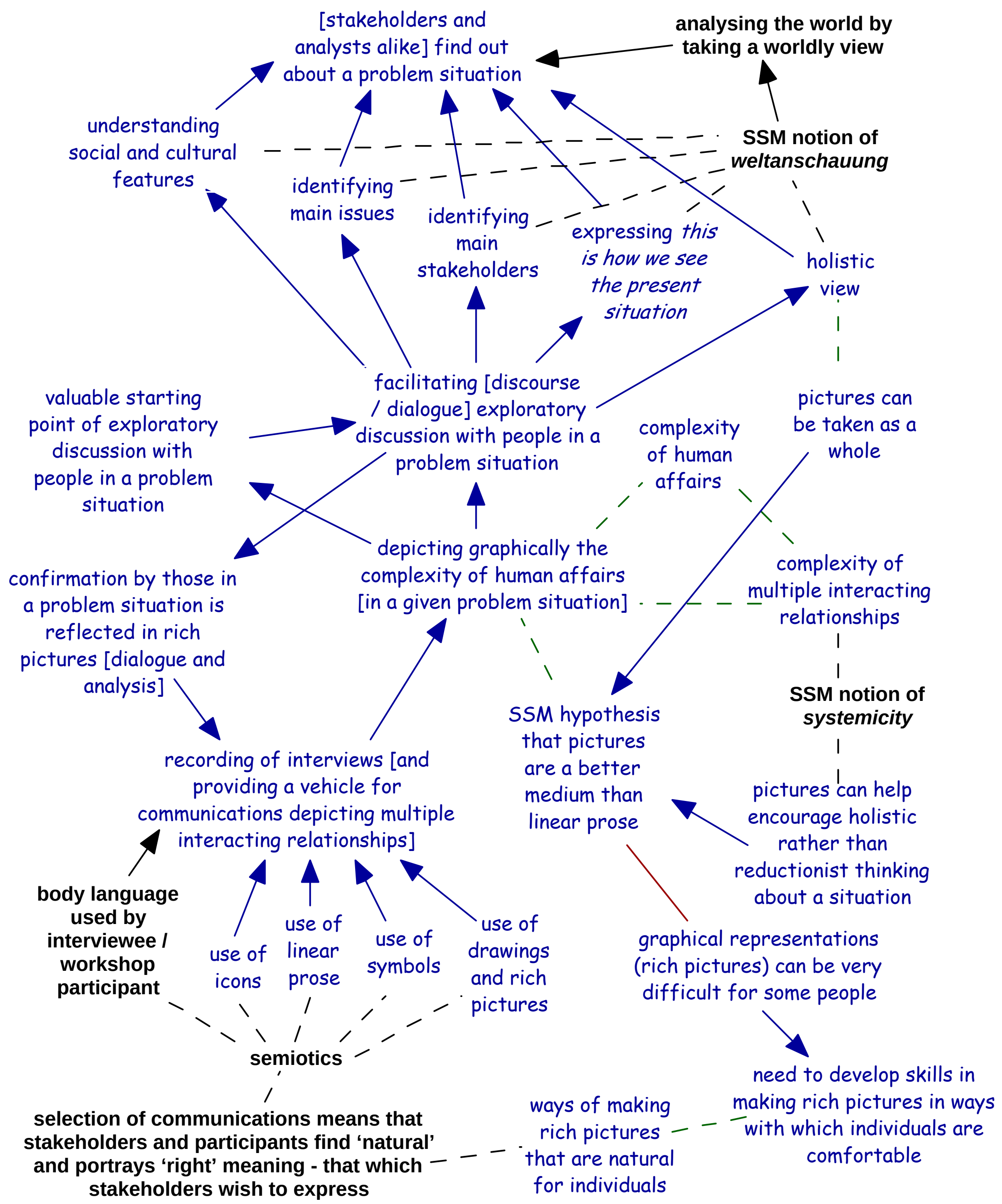


Figure 2-9. Finding Out About a Problem Situation (1) (2)

Notes:

1. This depiction of SSM has been derived primarily from the textual description contained in the 30-year retrospective in SSM (Checkland and Scholes, 1999: A15-A17), as interpreted by the author of this dissertation.

2. Detail shown in normal text is derived from the work of Checkland and Scholes. Augmentation, in bold, is that of the author of this Thesis.

An excellent review is contained in the 30-year retrospective (Checkland and Scholes, 1999: A3-A61). Rather, the map concentrates on the relationships and interaction between concepts upon which SSM has been developed, or has evolved over some 30 years.

Like Mason and Mitroff's SAST, SSM sets out to foster, through the systematic use of such intellectual devices, the surfacing of assumptions and mental models, and development of exploratory discourse among people who are grappling with a problem situation.

Checkland is emphatic that learning is central to SSM.

> [SSM is] a process of social inquiry which aims to bring about improvement in areas of concern by articulating a learning cycle (based on systems concepts) which can lead to action (Checkland and Scholes, 1999: A40).

Unfortunately, this important point is missed by many who perceive SSM simply as a step-by-step process. SSM is <u>not</u> a one-shot methodology. It is intended for iterative use, providing a vehicle for dialogue and discourse even as more and more becomes known about the problem at hand.

SSM is but one approach to finding out about a problem situation. Checkland admits that some people have difficulty with 'rich pictures' and training might be needed to develop their rich picture communications skills in a way with which they are comfortable. The extensive 'clip art' now offered with many desktop computer software applications offers a quick, effective, graphic means of producing rich pictures for those who cannot draw.

There are other alternatives to rich pictures as vehicles to facilitating communications, knowledge elicitation and surfacing assumptions. Systems thinkers use various methodologies employ devices to assist thinking and communication about systemic issues. These include hexagons (Hodgson, 1992; Lane, 1993a) and oval mapping (Eden and Ackermann, 1998). However, these are reliant on the use of language to describe concepts. Sutton (2000) warns of linguistic problems with requirements and knowledge elicitation and, hence, during problem conceptualisation. In an extensive study of results attained during group model building, Rouwette, Vennix, and van Mullekom

(1999) found, ‘insight’ was found to be the greatest effect achieved and development of ‘common language’ was the least. See Figure 2-10.

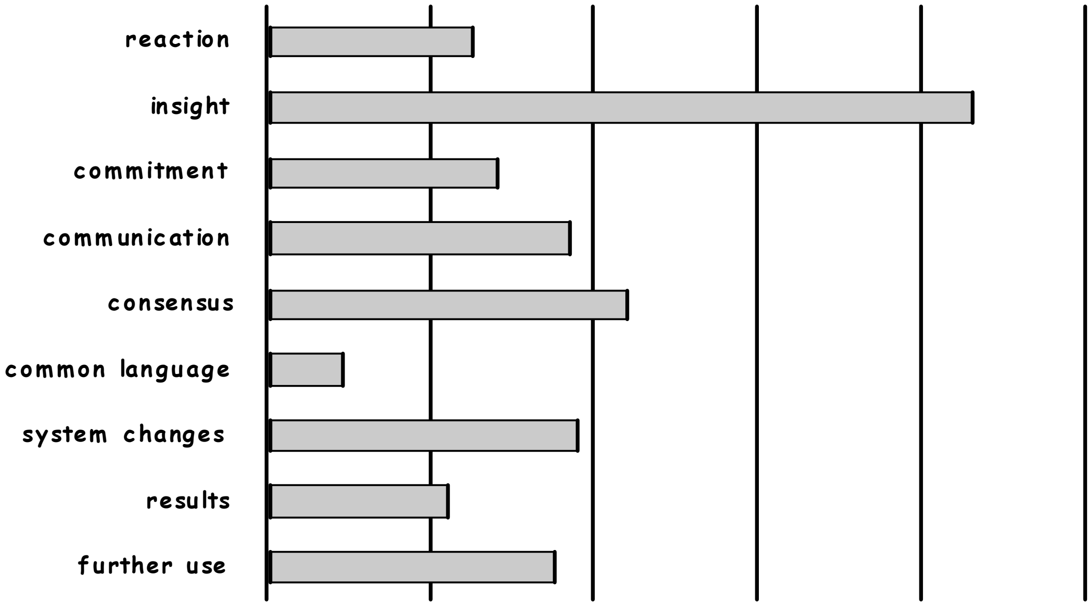


Figure 2-10. Common Language in Group Model Building

The similarity between SSM and Group Model Building (GMB) is that they both rely on icons and symbols, that is, semiotics is used to convey meaning. SSM uses rich pictures whilst GMB relies on commonly accepted icons representing *levels* and *rates* for material flow and *auxiliaries* for information flows. The ways *levels, rates* and *auxiliaries* are connected conveys a vast amount of meaning.

Churchman (1971) and Mason and Mitroff (1973) identify preferred modes of gathering and processing information generally used by decision-makers. Choice of which intellectual, semiotic devices to use and how to communicate should be informed by client preferences regarding gathering and processing of information. Further, communications must be facilitated in a non-threatening way. Knowledge elicitation, assumption surfacing and testing can be threatening to individuals. These activities demand highly effective communications skills among workshop participants and facilitators alike.

2.29 Problems of Paradigm Incommensurability

Lane and Oliva (1998) and Lane (2001) argue that the soft OR and system dynamics paradigms are incommensurable. The real, or perceived, extent of that incommensurability has contributed to ongoing arguments about qualitative *vs* quantitative modelling. Lane and Oliva (1998) and

Lane (2001) identify a number of 'problems' of paradigm incommensurability, stemming primarily from Lane's (1994: 53-66) proposition that there are fundamentally four different ways of making sense of the world, which have developed from man's diverse social and intellectual development:

a. *Radical Humanism*

b. *Radical Structuralism*

c. *Interpretative Sociology*

d. *Functionalist Sociology*

In Lane's topology, the engineering disciplines, and system dynamics modelling because of its origins in engineering control theory, broadly fit within the last group, *Functionalist Sociology*. '*Fin de siècle SD'* is an envisaged practice grounded in *interpretivism* and fits within *Interpretative Sociology*, and where 'modelling as a social process is embraced whole-heartedly … the models are nominalist representations which help humans create their social worlds via debate and the construction of shared meaning' (Lane; 1994: 62). Here we have to deal with the vagaries of social and cultural values, human reasoning, cognition and cognitive behaviour, fuzzy logic and bounded rationality. This is where the application of soft OR techniques is likely to be successful. Perhaps the best example of these soft OR techniques is the Soft Systems Methodology (SSM), discussed at 2.28. Other soft OR techniques are mentioned at 6.16.1 and 6.29. Advocates of SSM argue that we should take an holistic view, *weltanschauung*, of systemic problems, argue that we must recognise *systemicity*, the systems and systems-of-systems behaviour of the world, and take into account the complexity of human affairs. This is depicted diagrammatically at Figure 2-9. Models produced when we adopt an SSM approach are purely nominalist representations, relying upon intellectual devices that help us create understandings of our social world (Lane 2001: 107). In *Functionalist Sociology* interpretations of the world where physical laws apply and quantitative analyses can be made are most common: quantitative system dynamics fits within this paradigm.

Simply put, engineers and systems dynamicists would argue that in the 'real world' decisions have to be, and are being, made all the time. Every day activities of engineers and system dynamicists, impact upon and, in turn, are impacted upon by, social and political values. In this context, tools and techniques such as those described in this thesis, which might help us better understand the diversity of impacts on stakeholders and accommodate their inputs, need to be judged on their overall effectiveness in relation to a remedying a particular problem situation. Their fit within the topology of the philosophical model proposed by Lane is far is less relevant. The relationships between various soft OR intellectual devices, and with the system dynamics modelling paradigm, are depicted at Figure 6-4, and discussed at Chapter 6. In essence, this discussion ignores the philosophical issues raised by Lane, and Lane and Oliva, focusing instead on the practical inputs and outputs associated with the application of each device.

Lane (2001) and Lane and Oliva (1998) argue that it is culturally infeasible to apply the positivism of system dynamics modelling to within the *interpretivist* paradigm. They argue that there are no general concepts to measure, or model, using quantitative techniques. In soft OR, modelling is accepted as a personal experience, and as such can only be understood in its full richness. They argue that problems come when attempts are made to apply quantitative system dynamics modelling within soft OR. Lane and Lane and Oliver argue that, for integration of techniques to be possible, the application of the techniques and the changes that might flow must be ‘culturally feasible and ‘systemically desirable’ and that the latter must incorporate the notion of ‘dynamic coherence’. The author of this thesis interprets this as a form of information feedback, which continually and dynamically facilitates revisions in thinking about a problem situation. It is acknowledged that ill-informed mixing of techniques could be misleading, or worse. However, the approach taken in this thesis is to use the aggregated products of soft OR as the basis, the requirements definitions, for building system dynamics models. The notion of ‘dynamic coherence’ is implicit in IISD. How we set about achieving this in practice is both explained and demonstrated at Chapter 7, although Lane’s philosophical terminology is not used.

Regardless of the philosophical discussions about soft OR and quantitative system dynamics modelling, there remains a real need to bridge the gap between problem conceptualisation, for which soft OR is frequently used, and problem analysis, for which quantitative system dynamics modelling is frequently used. See Mingers and Gill (1997) and Mingers and Brocklesby (1977). This real and pragmatic need provides the impetus behind the attempts in this thesis to integrate qualitative and quantitative techniques. This thesis sets out in a practical and pragmatic way to demonstrate that there is a place in complex problem solving for judicious and informed use of both soft OR and quantitative modelling. Lane’s philosophical arguments are noted but it is not considered necessary to resolve them before proceeding.

2.30 Summary – Chapter 2

Significant gains accrue from careful attention to requirements, knowledge elicitation and problem conceptualisation. Action research suggests close stakeholder involvement from the very outset, from the earliest stages of conceptualisation, and this involvement should continue throughout model building and strategy development. Stakeholder involvement will enhance both understanding of the problems and commitment to strategy implementation.

There are many occasions when need to seek out stakeholder views and perspectives, and rely on them. We need to understand when these, and associated ingrained assumptions, might be flawed. Such awareness only comes from an understanding of complexity itself and a working knowledge of human cognition. This means we must be aware of how people use mental shortcuts in both quick and deliberate decision-making, and the difference between the two forms of decision-making. It also means we need to understand how various forms of cognitive behaviour may affect choices, decision and the way stakeholders act. We need to know how and when prejudice, bias, and politics might come into play. Given that these influences exist and come into play from time-to-time, we cannot trivialise problem conceptualisation without risk of basing model building activities on invalid, biased assumptions or inappropriate choices and decisions. Any successful problem-solving methodology we might like to devise cannot be divorced from considerations of the way people think and feel, culture, their prior experiences, and their deeply ingrained assumptions.

Before we can develop effective ways of dealing with complex, dynamic, systemic problems, we need to understand the nature of those problems. In Chapters 3 and 4, detailed analysis of a number of case studies will be used to reveal much about such problems. Chapter 5 will be used to expand our characterisation of these ‘wicked’ problems with the aim of setting the scene for developing methods we might employ to address them.

2.31 Significant Contributions Made in Chapter 2

Whilst this chapter does not seek to add materially to cognitive science, it does bring highly relevant recent decision research into the systems thinking and system dynamics arena. Informed arguments about the design of decision support systems for executive decision-makers cannot be built on ignorance about the way these people think and decide.

This chapter emphasises the importance of requirements engineering in the conceptualisation phase of a strategy development intervention. It also makes it very clear that major gains accrue from effective problem conceptualisation.

Nowhere in the literature are the influences on the ways decision-makers think and decide depicted as graphically as they are here. Unique concept mapping depictions of *Managerial Cognition*, Figure 2-3, *Systems of Knowledge-Power*, Figure 2-8, and *Finding Out About a Problem Situation*, Figure 2-9, provide quick and ready reference for designers of decision support systems and strategy development interventions.

Barriers to learning and effective decision-making are very real. The best strategies will fall on fallow ground unless when we design interventions we recognise the potential barriers. The list produced here, based partly on the literature and partly on the author's observations and experience as a management and a strategy development consultant, should be valuable to researchers and practitioners alike.

CHAPTER 3: WORST FAILURE - FAILURE TO LEARN: BLACK HAWK HELICOPTER CRASH CASE STUDY

Synopsis

As discussed in Chapters 1 and 2, decision-makers need help in dealing with complexity. To work out how we might provide that help, this chapter starts with an investigation of both the nature of complexity and how some people dealt with it. Insights derived from that investigation are intended to equip us for our quest to develop better ways of dealing with detail and dynamic aspects of complexity.

Events understood to have caused, or contributed to, recent man-made catastrophes were studied. Cases were chosen because they provide valuable insights into systemic failures, and because they were comprehensively documented. Records of extensive investigations by Royal Commissions, Boards of Inquiry and Coroner's Inquests are readily available and contain rich descriptions of systemic problems. They also highlight lessons about complexity we might find valuable. Most importantly, except that sequences of events under investigation invariably resulted in tragedy, the situations described in the Reports of Royal Commissions, Boards of Inquiry and Coronial Inquests are strikingly similar to many complex problems we are required to manage daily. This is discussed further at Chapter 4.

Threads common to each of the case studies here and in Chapter 4 are highlighted with the aim of focusing our decision-making, management and research efforts. As a mechanism for summarising the scope of this chapter, a concept map is at Figure 3-1.

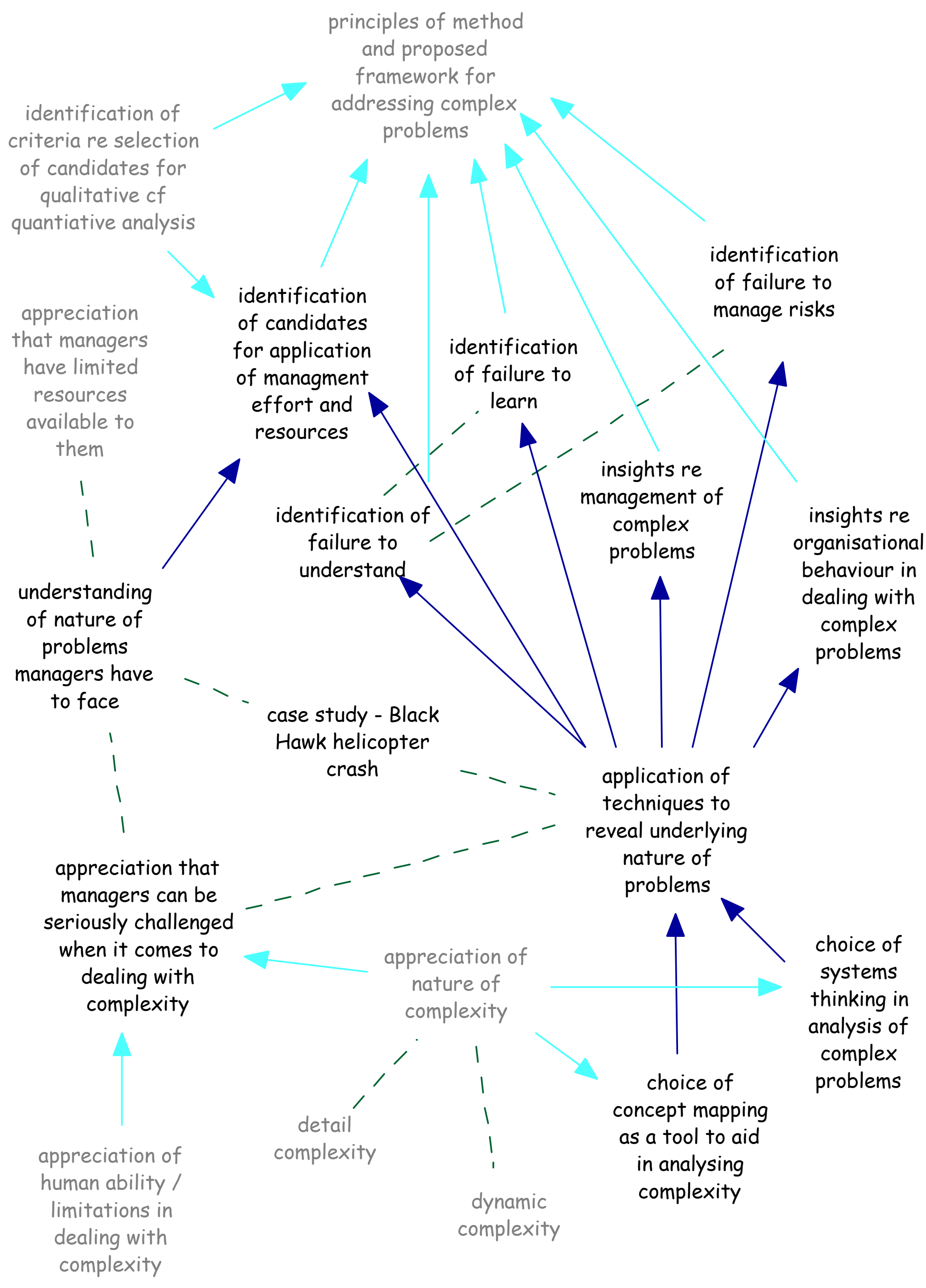


Figure 3-1. Concept Map - Chapter 3 (1)

Note:

1. Concepts shown in black text are contained in this chapter.

3.1 Accident Case Studies - Overview

On the evening of 12 June 1996, during a routine training exercise near Townsville in Queensland, two Army Black Hawk helicopters collided and crashed to the ground in a massive fireball. 18 soldiers died and 12 were injured (Australian Army, 1996). Many similar exercises had been practised, why did this one go horribly wrong? This case is examined in detail in this chapter.

One quiet Sunday afternoon in July 1997, young Katie Bender died when she was struck in the head by a fragment of steel having 100 times the energy of a bullet fired at point blank range. She, her family, and thousands of spectators had come to witness a highly publicised spectacle, the demolition of a community hospital in the centre of Canberra (ACT Magistrates Court, 1999). The shot-firer who laid the explosives was charged with manslaughter, but was he really responsible? Some wanted the Chief Minister of the Australian Capital Territory to resign, arguing she interfered and was responsible through her unwelcome involvement. This case is examined in detail at Chapter 4.

On 5 May 1998, a fire in the engine room of HMAS WESTRALIA resulted in the deaths of four Naval personnel. The fire was caused by diesel fuel from a burst flexible hose spraying onto a hot engine component. Flexible hoses of an unapproved type had been recently fitted to replace rigid metal ones which continually weeped small amounts of fuel (Department of Defence, 1998). A minor problem was fixed only to replace it with a much more serious one, with death being the consequence. This case is briefly examined at Chapter 4.

At about lunchtime on 25 September 1998, a heat exchanger in Esso's Longford Gas Plant No.1 fractured, releasing hydrocarbon gases and liquid. The resulting explosions and fire killed two workers and injured eight others (Parliament of Victoria, 1999). Gas supplies to millions of customers in the State of Victoria were disrupted for months. A safety audit conducted by the parent company Exxon only months before had given the plant a clean bill of health. This case is briefly examined at Chapter 4.

Questions we well might ask are… What lessons can be drawn from these accidents? … What can we learn about the detailed processes that led to the final tragic outcomes?

What decision aids might have assisted in revealing the interconnectedness of these problems?

Now that investigations are complete, what has become clear is:

a. each of these accidents was avoidable; and

b. numerous recommendations intended to avoid future catastrophes, were made.

Only time will tell whether lessons have been really learnt, whether recommendations were actually implemented, and if they proved effective.

The Reports of the Boards of Inquiry, Coronial Inquest and Royal Commission each identify a series of factors combining at a single culminating point, with catastrophic results. The naive might argue this was chance. Chance certainly played a critical part, but only in the terminal stages. First, the circumstances had to be created by man: only then could chance play its final tragic role. These precursor circumstances could have, and should have, been recognised and managed. If this had been done, the outcomes may have been quite different.

There is an interesting paradox here. It is highly likely, arguably almost certain, that by managing the precursor circumstances, those in positions of responsibility would have been able to avert tragedy. But, what had been successfully averted would have gone unnoticed. There would be little or no public acknowledgment that management action had been effective. Often, the consequence of this paradox is an attitude of complacency, or denial, that there are problems. Complex and difficult problems are treated like a Pandora’s Box. Many fear opening the Box, living in trepidation that they may not be able to comprehend what they will find. So they go through life largely ignorant of how systemic influences play themselves out.

Effective management strategies can only be built on a clear understanding of the forces at play and how they interrelate. Our focus, therefore, should be on identifying when and how forces are likely to combine to produce undesirable outcomes. Then, we can set about routinely managing to prevent the forces combining in an unfavourable way. This is risk management and it should be part of our problem-solving methodology.

The Black Hawk helicopter crash case study is used to demonstrate when, where and how we might apply risk management. The Board of Inquiry Report is reviewed using systems thinking and concept mapping techniques.

Common threads revealed as a result of these reviews are summarised at the end of this chapter. The preliminary research described here concludes that perhaps the greatest gains are to be made by enhancing our understanding what underlies complex, dynamic, systemic problems. In Chapter 5 the nature of these ‘wicked’ problems is discussed in detail.

3.2 Black Hawk Helicopter Crash - Case Study Overview

Military operations against an armed and determined enemy depend for their success on deception, surprise and shock action. This is particularly the case in Counter Terrorism (CT) where hostages are involved. Here, execution of an operation with absolute precision often means the difference between life and death, for soldiers and hostages alike.

High levels of precision cannot be achieved with confidence unless they are practised under conditions as close as possible to those which might be characteristic of an actual hostage incident. Such practice requires high levels of individual and team skills, and can be dangerous. Associated risks can never be completely mitigated without loss of training realism.

On that fateful day in June 1996, at the High Range Training Area near Townsville in Queensland during training to build individual and team skills required for CT and Special Recovery Operations (SRO), there was a catastrophic training accident. Two Black Hawk helicopters collided resulting in their destruction and the deaths of 18 members of the Australian Army, and injuries ranging from minor to very serious for 12 others.

The accident occurred on the second day of a series of training activities designed to develop and retain high readiness on the part of the Special Air Service Regiment and the 5th Aviation Regiment. These soldiers were training to undertake operations to recover Australian citizens should they become the victims of a hostage situation, such as has occurred in many parts of the World.

After the accident, an extensive and thorough Inquiry was conducted. It lasted three months. The Board of Inquiry Report and related proceedings comprise 17 volumes. In summary, the Board found that the accident was the inevitable culmination of a series of 16 directly causative factors. A further 26 factors were identified by the Board as having contributed. The Board made 79 recommendations intended to ensure such an accident does not recur.

3.3 Learning Opportunities Lost

Boards of Inquiry are tasked through their Terms of Reference to find causes, to identify why existing controls failed, and to determine who was responsible. In essence, apportioning blame has a high priority. Whilst it is necessary for legal and disciplinary reasons to determine if individual neglect contributed to the tragic outcome, Inquiries can produce unfortunate by-products as far as learning is concerned.

Understandably those touched by an accident or subsequent investigations may be emotionally stressed. When this happens, learning opportunities are lost.

Unless we all take deliberate action designed to minimise loss of learning opportunities, we are less likely to learn from past events, accidents, incidents or catastrophes, and use that learning to inform behaviour, decisions and strategies for the future. Massive gains may be achieved by facilitating the understanding and learning among managers and decision-makers, particularly. Equally, there may be substantial barriers to achieving this goal.

Of course, lessons can be found in the minutia of Reports of Boards of Inquiry, and the like. But, how many managers would have time to read the 17 volumes of the Black Hawk helicopter crash, for example? Few will ever read such Reports in any detail. Some may read a synopsis or an Executive Summary, or an article published in a newspaper or magazine.

There is an unfortunate heavy reliance on popular media coverage, such as TV, which all too often is biased, and sensationalist. As an extreme example, in October 1999, a 60 Minutes© TV programme was screened that was advertised as investigating the causes of the fire in the HMAS WESTRALIA, and lessons that might be learnt. When the programme’s transcript was analysed for concepts which might provide insights into the cause, and lessons to be learnt, only five concepts could be found. The remainder of the programme focused on emotional issues.

Evidence from case studies contained later in this dissertation would suggest that an executive overview of the accident should contain many more concepts, by at least an order of magnitude. There are many impediments to taking a systems view of complex issues, this is but one. This is discussed briefly here and in subsequent chapters.

3.4 Black Hawk Helicopter Crash – Executive Summary

To set the scene for discussion, the following was extracted from the Executive Summary of the Black Hawk Board of Enquiry 1996:

> **Preliminary Facts**
>
> 1. On Tuesday 12 June 1996, 1 Squadron Special Air Service Regiment (1 Sqn SASR) and A Squadron 5th Aviation Regiment (A Sqn 5 Avn Regt) were participating in a live firing Counter Terrorist/Special Recovery Operation (CT/SRO) exercise at Fire Support Base (FSB) Barbara in the High Range Area. This activity was part of Exercise DAY ROTOR 96 and was being conducted on the second day of the Exercise program. Training on 12 Jun 96 commenced at 1000 hours when orders were delivered to participants for the day's activities which were to be:
>
>   a. a day airmobile live fire assault on to FSB Barbara, incorporating live fire from fire support helicopters;
>
>   b. a day ground live fire assault on the same objective; and
>
>   c. a night airmobile assault, incorporating mortars, but otherwise the same as the day airmobile assault.
>
> 2. Six (6) Black Hawk helicopters from A Sqn 5 Avn Regt with an aircrew complement of 24 were committed to the exercise. A total of 43 1 SAS Sqn soldiers were involved in the airmobile assaults. These were to be effected by fast roping from four assault aircraft at points adjacent to gun emplacements at FSB Barbara, with fire support being provided from two aircraft on the flanks. The ground crew of 16 personnel consisted of Safety Officers and Administrative staff, predominantly from 1 SAS Sqn.
>
> 3. The day serials of the exercise were conducted without incident, although the objective was found to be more confined than pilots had expected from the orders and briefings they had received. In addition, some uncertainty existed in the mind of CAPT Burke, the flying pilot of Black 2, about the respective locations of Black 1, Black 2 and Black 5 in relation to the gun emplacements. This uncertainty may have been caused by an inaccurate whiteboard diagram of FSB Barbara which had been used in the orders and briefings at Garbutt prior to commencement of the exercise. Having expressed his concern to CAPT Hales, Flight Lead in Black 1, CAPT Burke discovered that Flight

Lead did not share his concern, and a compromise solution was reached between the two pilots to go to the same positions for the night mission that had been used during the day.

4. Although the night mission was supposed to replicate the day airmobile assault, some changes to the day mission's profile, to mask the approach and noise of the helicopters and to give fire support aircraft more time over the target, were requested by SAS personnel. A proposal by Flight Lead to use a different formation in a river valley further to the West of the day track was refused by OC A Sqn, MAJ Jameson. However, a decision was made to release the flanking fire support aircraft earlier than by day and, before launching the night mission, Flight Lead briefed aircrews that he would fly lower from the Initial Point (IP) than during the day.

The Accident

5. At 1830 hours, the formation departed FSB Barbara and headed south before making a wide Left turn to intercept the IP and commence the run-in to the FSB. The track adopted was to the Left (West) of that used during the day by some 300 metres. All of the preparatory and formation calls were transmitted and at the 30 second call, which was given approximately 1 to 1.25 minutes from the objective, the formation changed to line abreast with Flight Lead in Black 1 on the Left and Blacks 2 and 3 formating to the Right of him at a separation of two rotor diameters (33.5 metres) between rotor discs. Black 4 positioned at the centre rear, astern of Black 2 and the Fire Support aircraft, Blacks 5 and 6, accelerated ahead of the assault formation towards their firing positions.

6. The formation approached FSB Barbara to the Left of the day track and at a lower altitude. Flight Lead was not informed by the pilots of any of the other aircraft that he was off track. Because the approach was different, visual cues were difficult to acquire under Night Vision Goggle (NVG) conditions. Additionally, identification of the gun emplacements on the FSB was hampered by the lack of aboveground features and the shadow cast over the objective by high ground to its West which was still backed by sunset skyglow. The gun emplacements became visible to NVG observation only in the final few hundred metres of the formation's track.

7. By the 30 Second call, the formation was about 400 metres off track and just prior to the call, Flight Lead made the first of three adjustments to the Right to bring the formation onto the target. The second of these Right turns was made just after the 30 second call and caused the convergence between Black 1 and Black 2. This was

detected by the aircrew in both aircraft and separation restored. Black 1's third manoeuvre to the right brought it into collision with Black 2.

8. Because of unfamiliar and confusing visual cues, it is likely that CAPT Hales misidentified his gun emplacement and turned Right towards the roping point of Black 2. His aircraft converged on Black 2 which was maintaining the previous heading of the formation. The entire formation had decelerated from 100 knots and possibly during this deceleration and the previous two Right turns, Black 2 had moved slightly ahead of Black 1. In any case, Black 1 approached Black 2 from behind and slightly lower, where its crew would have had difficulty seeing Black 2. SGT Mark, Black 2's Lefthand Loadmaster saw the approach of Black 1 moments before impact. He called "Come right, come right, come right", then "Come up, come up" as Black 1 began to pass beneath Black 2 from behind. Black 2's Pilot had little time to react and, being unaware of Black 3's position, believed that he could not turn Right. He had applied aft cyclic to climb just as Black 1's Pilot attempted to take avoiding action, banked Left and struck the aft sections of Black 2 with its Main Rotor.

9. Black 1's main rotor blades were destroyed mid-air. Their strikes on Black 2 severed its tail boom, ruptured one of its fuel tanks and fractured the support structures of the aft section of the passenger compartment. Fuel sprayed from Black 2 and ignited causing a huge, instantaneous fuel/air explosion. Fire was also ignited in the severed Tail Boom of Black 2 and fuel spewed into the passenger compartment. Black 1 continued to roll to the Left and crashed to the ground enveloped in flame. It impacted the ground inverted and was consumed by fire. Black 2 went into a flat spin, revolving clockwise a number of times, before impacting in an upright position facing generally in the direction of its flight path. Fire from the burning rear section spread forward through the fuel-saturated main body, eventually engulfing and destroying it.

10. Very effective rescue efforts were made immediately the aircraft crashed to the ground. Casualty treatment, classification and evacuation were organised very well. Nevertheless, three aircrew and eight passengers in Black 1, and seven passengers in Black 2, died as a result of this mid-air collision.

Causes

11. Although the collision sequence described above reveals that the terminal cause of the accident was the convergence of Black 1 into Black 2, the Board has found that there was a Chain of Events that successively and cumulatively created the conditions and environment in which the accident became and inevitable outcome. All of the factors and events in the chain untimely combined in one fatal culminating point. The

following is a synopsis of the Board's Findings an are the notable links in the chain which constitute causes contributory to the final actions which brought the two aircraft into mid-air collision:

a. aircraft unserviceability in 1994/95 which reduced the opportunity for pilots to gain experience and proficiency in flying CT/SRO missions;

b. high pilot separation rates which further eroded the experience base within 5 Avn Regt;

c. inadequate and untimely joint exercise planning between SASR and 5 Avn Regt;

d. inadequate supervision and checking of delegated exercise planning tasks by responsible superior commanders;

e. incomplete and uncoordinated reconnaissance of the exercise site, including inadequate air photography of FSB Barbara;

f. inaccurate diagrammatic representation of FSB Barbara which was used for briefing both SASR ground assault teams and 5 Avn Regt aircrews;

g. changing flight profile and direction for the night mission from that which had been practiced in the day airmobile assault;

h. employing a complex flight formation which permitted no individual aircraft manoeuvre flexibility, and with no abort procedure practiced, under NVG conditions on a tight objective with no vertical identifying features;

i. appointing an inexperienced Flight Lead to lead the formation on a combined arms, live firing, NVG, three aircraft abreast airmobile assault mission;

j. failure of the Air Element Commander (AEC) to exercise command and control of the formation in the air because of his involvement as the flying pilot of one of the assault helicopters; and

k. failure of the AEC or any other pilot to inform Flight Lead that he was off track and that difficulty in identifying individual roping and firing points was being experienced.

Recommendations

12. At Part 5 of this Report, the Board makes a significant number of recommendations with the purpose of advising those remedies which it considers necessary to ensure compliance with regulations, safety in training and implementation of, and adherence to, "best practice" procedures. Above all, these recommendations are designed to ensure that Army can continue to satisfy all its capability and readiness requirements, including those involving high risk, while also ensuring that the circumstances which caused this accident can never be repeated.

13. In summary, the Board's recommendations attend to the following matters:

a. Risk Analysis;

b. Australian Defence Force (ADF) and Army Directives and Plans for CT/SRO;

c. command and control relationships between SASR / 5 Avn Regt for CT/SRO;

d. information gathering responsibilities for CT/SRO exercises;

e. attendance at exercise orders and briefings;

f. conduct of missions requiring use of NVG equipment;

g. aircrew training for CT/SRO and maintenance of proficiency;

h. technical control of flying operations;

i. equipment acquisition and maintenance;

j. personnel and logistics remedies;

k. tasking priorities for 5 Avn Regt;

l. responsibilities of Army Accident Investigation Team (AIT); and

m. disciplinary action against persons affected.

3.5 Mapping of Factors Contributing to the Accident

A form of mapping was used to analyse various causal contributions. Mapping techniques have been developed by systems thinkers to map causality and interrelationships. These techniques are not new. They have been used in various forms for decades. It will be shown that we have not harnessed the full potential of mapping as an analytical tool, and there is scope for mapping as part of an integrated, qualitative and quantitative, problem-solving approach.

The main technique used here is concept mapping. An important benefit of concept mapping is that factors relevant to a particular viewpoint can be graphically depicted on a single piece of paper. This helps us cut through the sheer volume of detail contained in Reports such as those, which present the findings of Boards of Inquiry, Coronial Inquests and Royal Commissions. It helps put many factors and interrelationships into context. It also allows us to quickly see where boundaries are already set, or might be set.

Concept mapping concentrates information. Concept mapping makes it both possible and practical to extract relevant concepts and causal relationships from various parts of the 17 volumes of the Black Hawk helicopter crash Board of Inquiry Report, and depict them in a few pages. Concept maps are invaluable also as aids to detecting logical errors in arguments, and omissions. It was considered most appropriate to analyse the key findings of the Black Hawk helicopter crash Board of Inquiry by mapping concepts. That is demonstrated below.

These maps will be referred to as *concept maps* rather than *cause maps, influence diagrams, causal-loop diagrams,* or *directed graphs* that are found in the literature. Indeed, the term concept map is both appropriate and correct. There are differences between these maps, diagrams and graphs. Differences are discussed in a later chapter of this dissertation.

At this point, it is necessary to take a slight procedural diversion to explain some differences. Mapping is used to bring various concepts into view, and to understand their interrelationships. When dealing with hard physical problems we seek to define relationships between parameters using algebraic expressions. In concept mapping we are dealing neither with parameters nor relationships, which are easily expressed in algebraic terms. Jacobsen and Bronson (1987) make the following observation about this:

> In their guidelines for causal-loop diagramming, Richardson and Pugh (1981: 28) recommend that one "think of variables in causal-loop diagrams as quantities that can rise or fall, grow or decline, or be up or down. But do not worry if you can not readily think of existing measures for them." This is misusing the term *variable*. A quantity

without measurable units is not a variable; it is a concept or a nominal definition of a concept (Jacobsen and Bronson, 1987: 4).

3.6 Map Building Basics

To build a concept map of the findings of the Black Hawk helicopter crash Board of Inquiry, we start by considering paragraph 11 a. – k. of the 'Causes' quoted above. A relatively simple set of rules are needed to build and interpret a map, they are:

a. Individual concepts are numbered for identification purposes only. Numbering is not intended to suggest importance or priority.

b. Where a choice exists for placement of concepts on a map, more important ones should be placed towards the top. This is balanced against the need for overall compactness of the map, which may require concepts to be positioned adjacent. Maps are easier to understand when read from the bottom up.

c. Causal relationships between numbered concepts are represented by arrows, where each arrow means 'leads to…'. See Annex A.

d. Connotative relationships, where causality may act in either direction at different times, are depicted by dashed lines (normally) without arrowheads. Further, causality may be ill defined and, hence, open to interpretation.

e. Conflicting relationships, a particular case of the connotative relationship, exist when concepts at the opposite ends of a line have a state of stress between them. Conflicting relationships are depicted by a solid line without arrowheads, or are dotted lines marked with the word 'CONFLICT'.

f. Delayed effects may be signified by a number of conventions. Here, a 'T' will be used to signify temporal causality. In maps depicting higher levels of aggregation, temporal causality may be omitted without loss of meaning. We might consider every causal link to have some delay associated with it: few things in human systems, those involving man and his actions, occur without delay.

We can start anywhere, but for convenience we will start with 11.a.:

> a. aircraft unserviceability in 1994/95 which reduced the opportunity for pilots to gain experience and proficiency in flying CT/SRO missions;

This contains two concepts *aircraft serviceability in 1994/95* and *reduced opportunity for pilots to gain experience and proficiency in flying CT/SRO missions*. This is depicted using the 'leads to …' logic, where an arrow (→) replaces the notion of 'leads to…', as below and in Figure 3-2:

> *aircraft serviceability in 1994/95* → *reduced opportunity for pilots to gain experience and proficiency in flying CT/SRO missions*

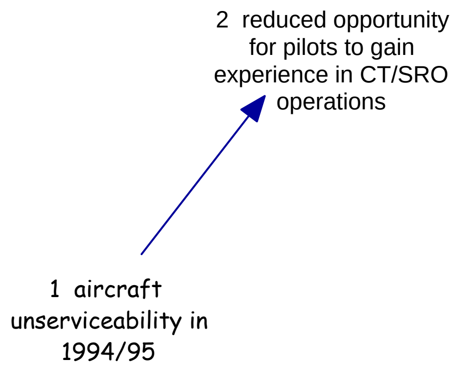


Figure 3-2. Relationship Between Aircraft Unserviceability and Opportunity for Pilots to Gain Experience

Similarly, 11.b. can be depicted as shown below, and in Figure 3-3:

> *high pilot separation rates* → *erosion of experience base with 5 Aviation Regiment*

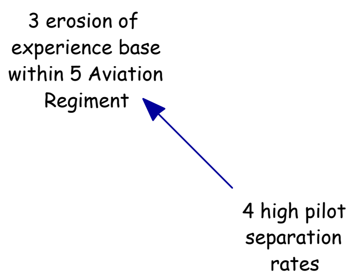


Figure 3-3 Relationship Between Pilot Separation Rates and Erosion of Experience Base

Those pairs of concepts linked by unambiguous causality can be progressively built into chains. These do not have to be complete at this stage. However, the critical requirement is to check that every link can withstand scrutiny of validation that one concept 'leads to …' the connected concept as shown by the direction of the arrow. As the map develops it might appear as depicted at Figure 3-4, noting that the diagram may have to be redrawn several times to tidy it.

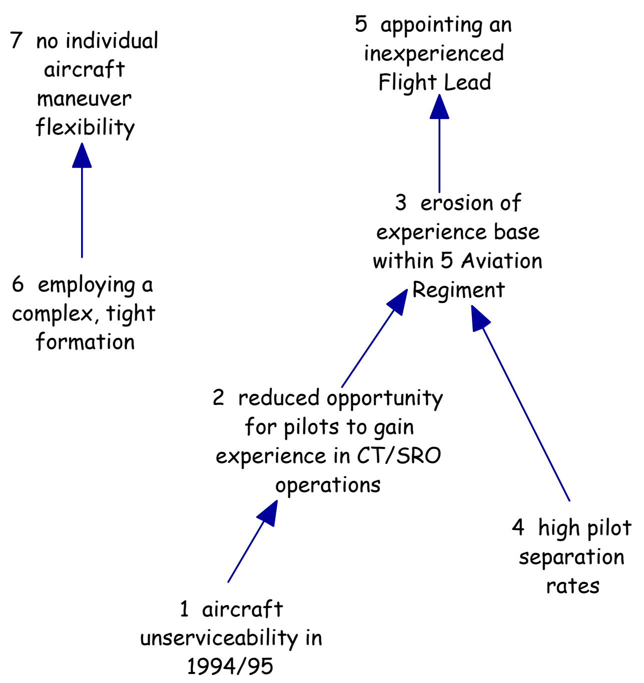


Figure 3-4. Incomplete Concept Map Showing Causal Chains and Temporarily Disconnected Concepts

An alternative is to write concepts on individual Post-it® Notes. These can be placed on a whiteboard, firstly in clusters of associated or similar concepts, then connected by arrows to depict causality. This technique works well in a group setting, or workshop. Eden and Ackermann, use a variation on this, which they call the *Oval Mapping Technique* (Eden and Ackermann, 1998: 303-320).

As map building proceeds, some concepts are found not to fit within the 'leads to…' logic without some form of ambiguity. In such cases, concepts are linked to the causal structure using a connotative link. An example is 11.c.:

c. inadequate supervision and untimely joint exercise planning between SASR and 5 Avn Regt

This has a logical link to Concept No 2 in Figure 3-4, *reduced opportunity for pilots to gain experience in CT/SRO operations*, but the nature and direction of causality is unclear. Also see Figure 3-5. Determining the exact nature of the link, and direction of causality, if any, is a little more difficult than with ordinary causal links. This demands thinking about possible circumstances where causality might manifest itself in different ways.

For example, we might ask questions like ...did *reduced opportunity to gain experience in CT/SRO operations* occur before, after, or concurrently with *inadequate and untimely joint exercise between Special Air Service Regiment and 5 Aviation Regiment*? To be able to answer this and similar questions requires closer analysis of the Board of Inquiry Report.

In the interim, the link is depicted legitimately as a connotative one, even though further analysis is needed. Connotative links almost always suggest a need for detailed investigation. This will be explained further when we look at building quantitative models based on the logic suggested by, or depicted in, concept maps.

Figure 3-5 depicts all aspects of causality gleaned from the Executive Summary of the Board of Inquiry Report. Scope, boundaries, and level of aggregation were pre-determined by the obligation the Board of Inquiry had to the Chief of Army according to their Terms of Reference.

Concept maps serve to present concepts graphically and to facilitate detailed step-by-step analysis. Individual maps accommodate differing points of view. Used carefully and consistently they are very useful in highlighting omissions and errors in logic.

The structure of Figure 3-5 appears hierarchical, which might be interpreted as reflecting strong causality. Such an interpretation may be flawed. Further information is needed to assist in reading and understanding the map.

3.7 Analysis of Executive Summary – In Brief

Reading of the map of the Executive Summary, Figure 3-5, could start at any point, although starting from the bottom is recommended. Causal links should be read first. Consider each series of links, starting with, say, Concepts No 1 → 2 → 3 → 5 → 21 → 24 → 28 → 27. Follow each series of links through until each has been read and understood. The next step involves considering the relevance of individual concepts.

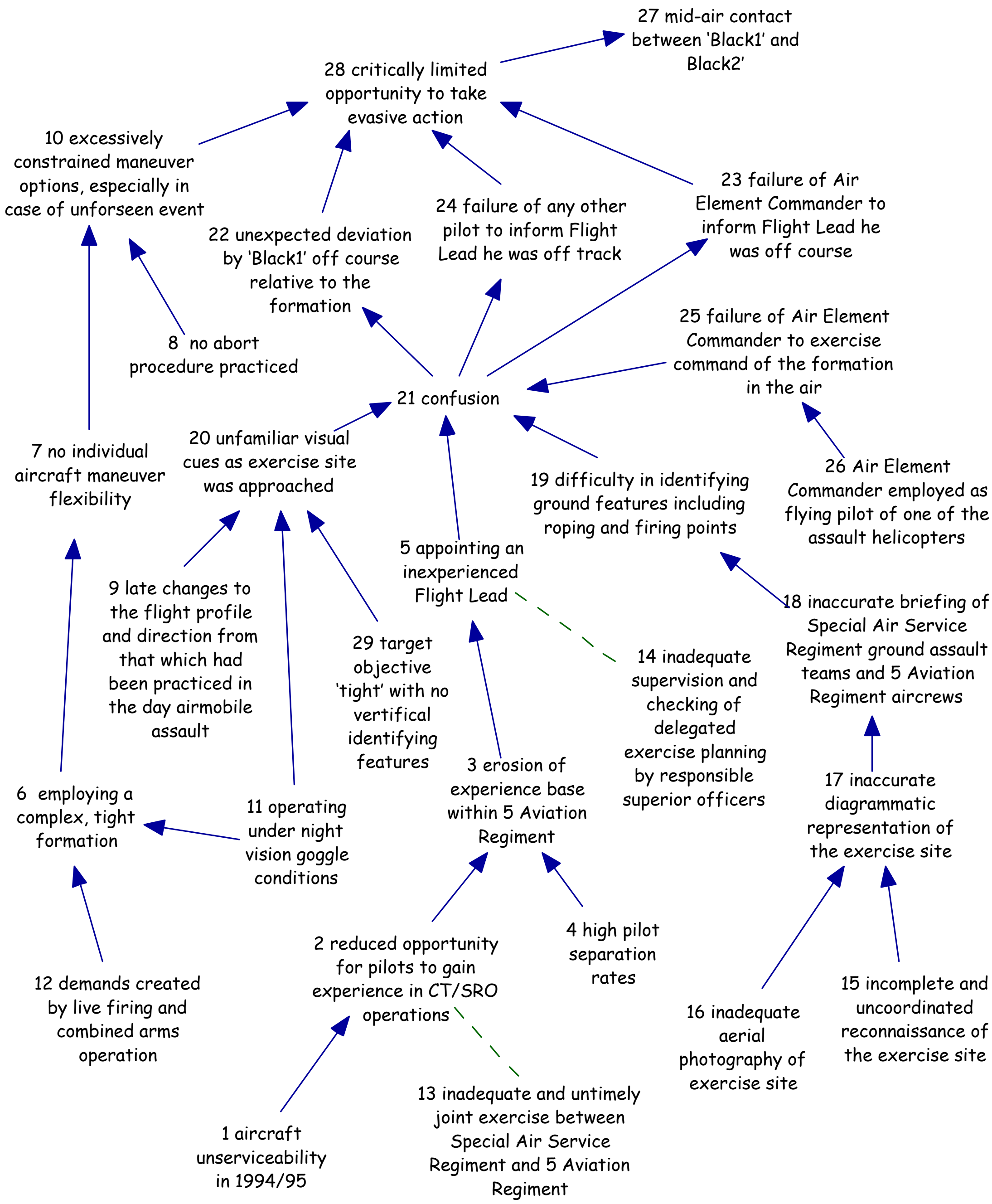


Figure 3-5. Executive Summary - Contributions to Mid-air Collision

3.8 A Call for Quantification of Causal Linkages

Unfortunately for the sake of this research, the Board did not assign weightings to causal links. In his report to the Minister for Defence, the Chief of Army commented on those 16 directly causative factors and the 26 contributory factors as follows:

> The linkages established by the Board are reasoned and reasonable, but are also contentious in the sense that the weighting given to each factor is not clearly established in the Report and therefore, the paths which lead to the inevitability of this accident are likely to be the subject of some controversy, particularly where they are alleged to include issues of individual neglect. (LTGEN J.M. Sanderson, CA 102/97 dated 22 Feb 97).

In reporting to Chief of Army, the legal advisor to the Board of Inquiry (BOI) made the following observations:

> 13. The BOI did not attribute the accident to a "single catastrophic event". Rather, it identified some 16 causes and 26 contributory factors. The BOI offers no criteria which led it to place matters in one category rather than the other. It is difficult to discern the basis upon which the distinction is based. For example, it is not immediately obvious why "probable misidentification of a target due to an incorrect mental model of the objective on the part of the flight lead" is considered a primary cause of the accident when "an objective which proved exceedingly difficult to identify in the prevailing light conditions under [Night Vision Goggles] NVG" is found to be merely a contributory factor. Similarly, there is no apparent reason for identifying "inadequate planning for the air mission on 12 Jun 96" as a primary cause of the accident and "inadequate combined planning for the airmobile mission on 12 Jun 96" as a contributory factor.
>
> 14. In identifying the primary causes of the accident the BOI did not seek to suggest any particular order of significance. This is unfortunate. Nonetheless, it is clear that the immediate cause of the accident, as found by the BOI, was Black 1 turning right, converging on Black 2 and coming into collision with it. Black 1's main rotor blades came into contact with the tail and fuselage of Black 2. There were five strikes. The main rotor blades of Black 1 were severed and it plummeted to the ground. The tail rotor section of Black 2 was severed and it crashed some 5 to 10 seconds later. **These events, in my opinion, constitute the primary causes of the accident.** The other factors which are so characterised in the report (with the possible exception of the finding that the helicopters were flying off track in their approach and did not adopt a heading which would re-intercept the track, thereby significantly changing the final approach track to the objective compared with the rehearsed approach) should, in my view be considered as contributory factors.

There is a growing interest in the quantification of concept maps, causal-loop and influence diagrams. A number of authors have suggested a need for adding weightings, or some form of quantification, to each link to indicate the magnitude of influence one concept has on other connected concepts. Comments, above, by the legal adviser to the Board of Inquiry clearly indicates he would like to see such analysis. This is addressed at Chapter 11.

3.9 Chief of Army's Report to the Minister for Defence

The concept map for the Chief of Army's Report to the Minister for Defence is at Figure 3-6. Rather than depicting the views of the Board of Inquiry alone, this map contains the Chief of Army's perspective, reflecting his somewhat broader remit. Figure 3-6 provides greater insight, introduces a number of related issues, and provides different emphasis. Chief of Army is entitled, by virtue of his position, to add emphasis without reference back to members of the Board. However, the balance achieved by addition of such emphasis needs to be critically reviewed rather than simply accepted on face value.

By way of comparison between this and the earlier map, see Concept No 4, *high pilot separation rates*, in Figure 3-5. In the earlier map this is shown as leading to *erosion of experience base within 5 Aviation Regiment*, but there is little other information about the problem. Further, it should be noted that this Figure 3-6, in particular, depicts on a single sheet of paper, months of detailed investigation and deliberation: close scrutiny is demanded. When the whole map has been read and understood, the overall structure should be viewed by standing back from the detail. See Figure 3-7, below.

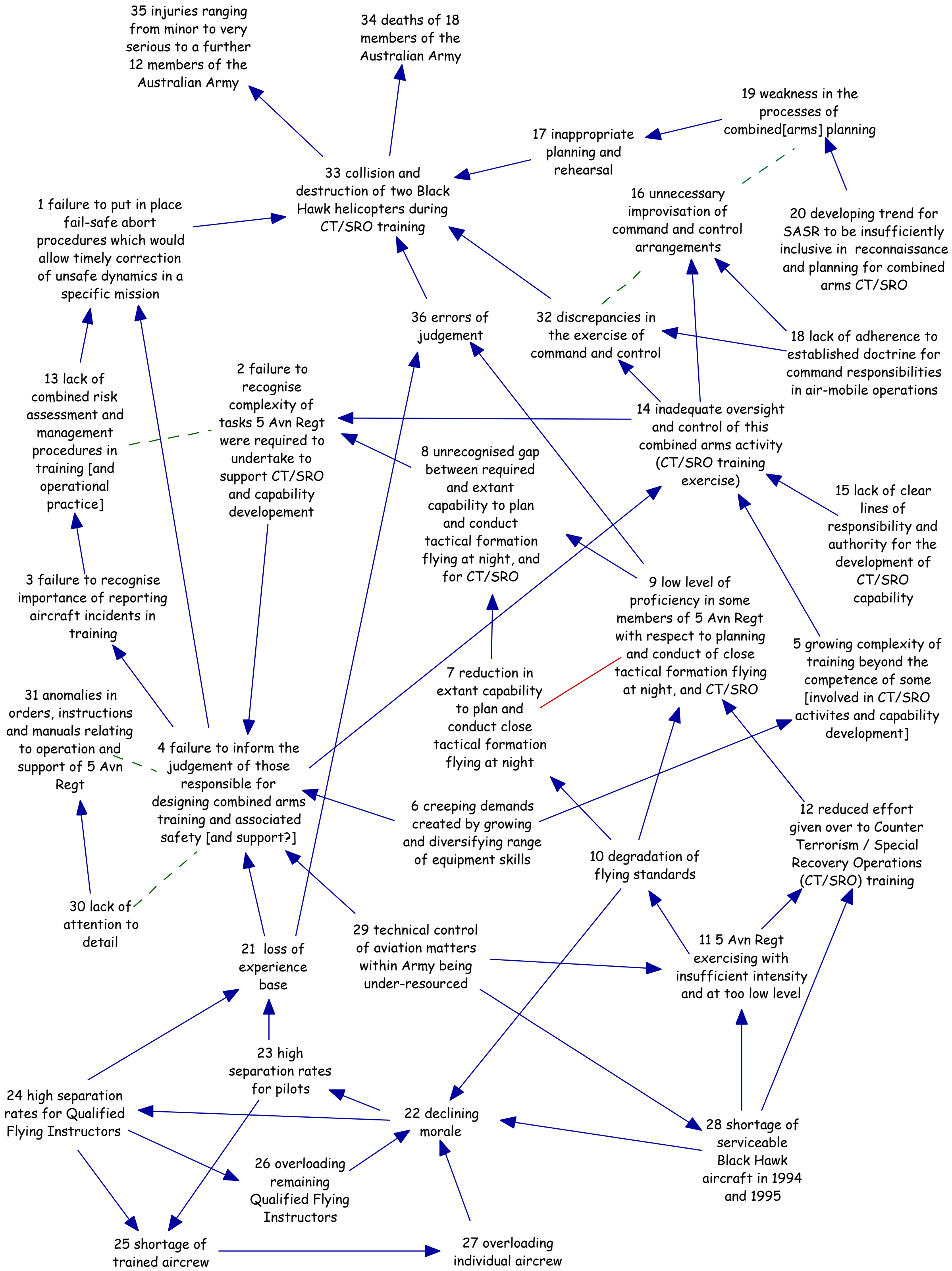


Figure 3-6. Concepts Included in Chief of Army's Report to the Minister for Defence

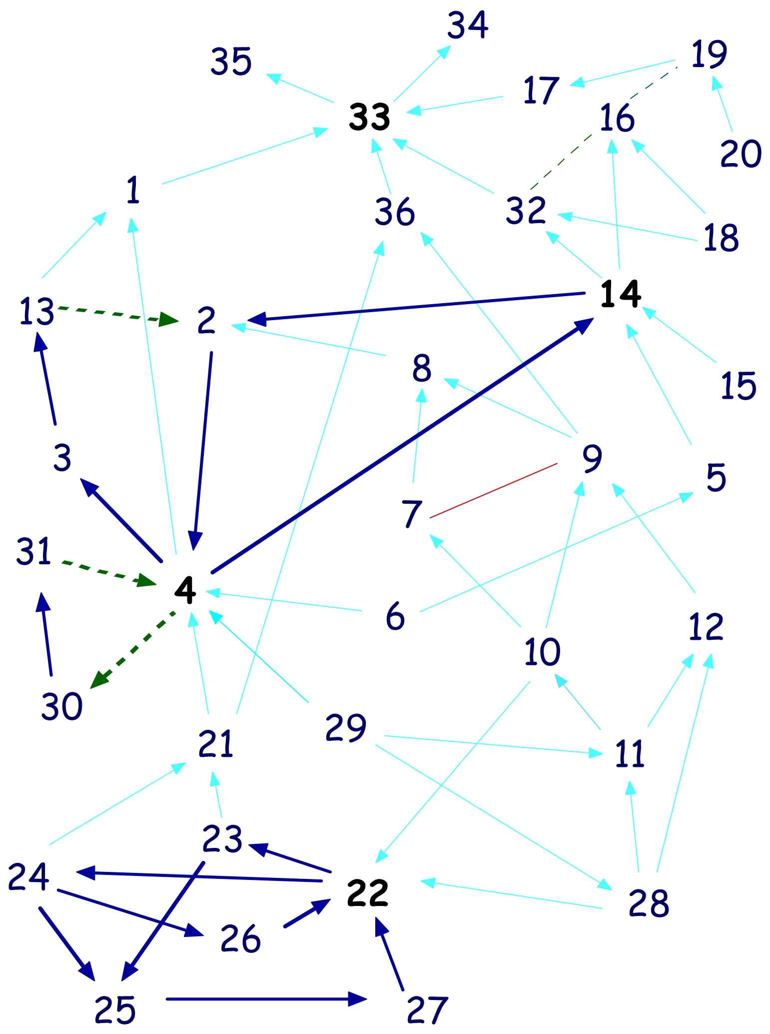


Figure 3-7. Structural Overview of Chief of Army's Report to Minister (1)

Note:

1. Arrowheads have been placed on connotative links to depict the direction of influence under consideration at this instant.

One way of enabling this consideration is to view the map as numbers linked by arrows and lines, without any text. This facilitates thinking about:

a. concepts connected in causal loops, such as 22 → 23 → 25 → 27 → 22, 22 → 24 → 25 → 27 → 22, and 22 → 24 → 26 → 22;

b. nodes where several arrows enter or leave, such as 4, 33, 22, 14, shown in bold, with nine, six, six and six linking arrows or lines respectively; and

c. concepts connected in loops involving a mix of causal and connotative links, where the latter are considered as bi-directional causal links following direction of the loop at least some of the time, such as 4 → 3 → 13 -- 2 → 4 and 4 -- 30 → 31 -- 4.

3.10 Building Management Strategies

Figure 3-5 and Figure 3-6 complement each other. When read together and compared, and structure is considered, as in Figure 3-7, these maps provide insights into where efforts might have been directed to avoid tragedy. Just how this might have been done before the accident, thereby averting tragedy, is explained below.

3.11 Accommodating Different Strategies

It is important to recognise that Figure 3-6 depicts a perspective different to the Board's Executive Summary and brings in other concepts considered important by Chief of Army. This does not conflict materially with any findings of the Board of Inquiry, but stresses Chief of Army's concerns and reflects his responsibilities to the Minister. This is Chief of Army's personal view. Vickers, 1970; Checkland, 1990; Vennix, 1996; Coyle, 1997; Eden and Ackermann, 1998; and others have noted the significance of differing perspectives. In human systems, there can be many valid perspectives of the same problem. The consequences of the need to accommodate a variety of perspectives can be quite profound for design and development of decision support systems.

3.12 Insights Derived from Feedback Loops

Contemplation of Figure 3-7 structure reveals several circular feedback loops. One is shown at Figure 3-8, below.

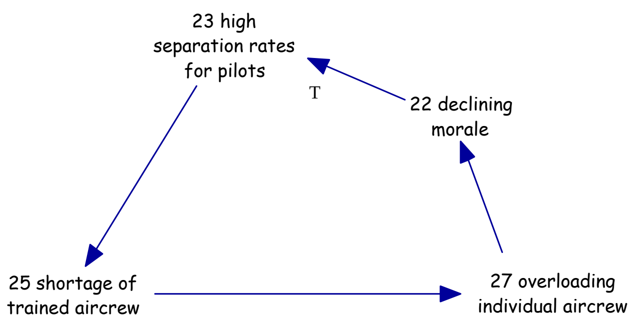


Figure 3-8. High Pilot Separation Rates and Declining Morale

Interrelationships might be interpreted as follows … *high separation rate for pilots* led to, or resulted in, *a shortage of trained aircrew* which, in turn, led to *overloading of the remaining individual aircrew*, and this led to *declining morale*, which after a delay led to *high* *separation rates for pilots.*

It should be noted that temporal causality, designated by 'T' does not appear in Figure 3-6 because that map depicts a higher level of aggregation. In a feedback loop such as this, there is no start point and no end point.

We might summarise the loop as Concepts No 22 → 23 → 25 → 27 → 22: *declining morale → high separation rates for pilots → shortage of trained aircrew →→ overloading individual aircrew → declining morale.*

Figure 3-9 builds on Figure 3-8 to include the following loops:

a. Concepts No 22 → 24 → 26 → 22: *declining morale → high separation rates for Qualified Flying Instructors → overloading remaining Qualified Flying Instructors → declining morale*, and

b. Concepts 22 → 24 → 25 → 27 → 22: *declining morale → high separation rates for Qualified Flying Instructors → shortage of trained aircrew → overloading individual aircrew → declining morale.*

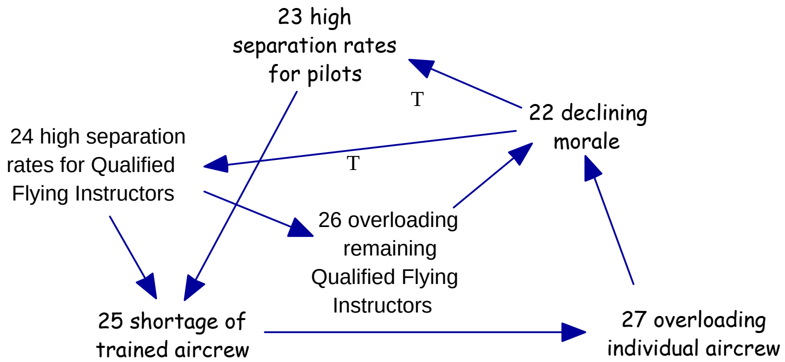


Figure 3-9. Loops Involving Declining Morale

This serves to highlight that several factors impacted upon morale, making morale decline progressively. These are positive feedback loops. They reinforce the effect of declining morale. As morale declines, pilots feel compelled to leave. When they do they create a greater shortage of trained aircrew. That increases the overloading of individual aircrew who become increasingly despondent with their plight, become more inclined to seek alternate employment. They, too may leave. A similar situation existed for Qualified Flying Instructors.

As the picture grows, we consider other links to declining morale, from Concepts No 10 and 28, as depicted in Figure 3-10.

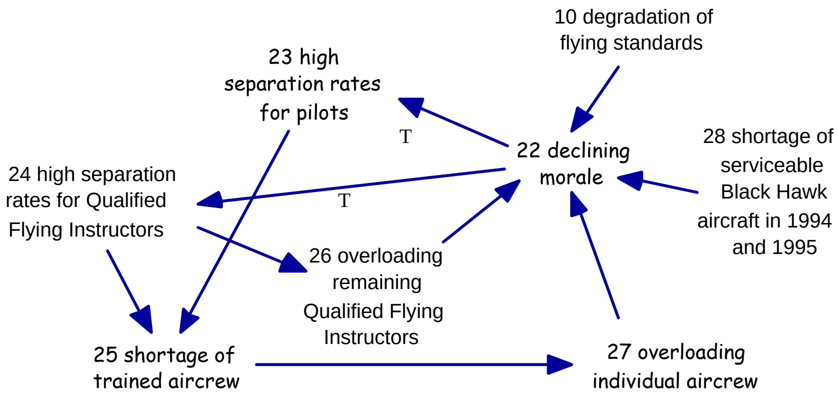


Figure 3-10. Expanding Consideration of Contribution to Declining Morale

We now see that *a shortage in serviceable aircraft in 1994 and 1995* contributed to *declining morale*, as did *a degradation of flying standards*.

Logic suggests there should be a link between *available numbers of Qualified Flying Instructors*, not shown, and *degradation of flying standards*. A concept, *available numbers of Qualified Flying Instructors* is not shown because the detail was not contained in the Chief of Army's Report, but the nature of that interrelationship would be discovered had further, and more detailed analysis been undertaken. A logical omission from the Executive Summary has been discovered?

3.13 Main Purpose – Identifying Where to Apply Management Effort

This brings us to the main purpose of presenting concepts and their interrelationships in these maps; to help us identify where to direct our efforts in order to understand and manage extant problems.

If were to commence quantitative analysis at this point, *available numbers of Qualified Flying Instructors,* would be a stock, level or accumulator. Similarly, *available numbers of pilots* and *available numbers of helicopters* would be stocks, levels or accumulators of interest. Quantitative models would be built with the intent of informing strategies for achieving and maintaining appropriate numbers of pilots and instructors, and their levels of operational competence to fly CT/SRO missions. This is discussed further, below.

What the Board of Inquiry did find in respect of aircrew shortages is contained in Part 3 of Volume 1 of the Board of Inquiry Report:

> **Aircrew Shortages**
>
> **3.251.** The Board received consistent testimony regarding aircrew shortages, particularly with respect of [Qualified Flying Instructors] QFI and [General Service Officers] GSO. The shortage of QFI was quoted as being the reason that CAPT Burke had handed over the Flight Lead to CAPT Hales, in order to reduce CAPT Burke's workload. The shortage of GSO was quoted as being the reason the CAPT Berrigan was [Operations Officer] OPSO A Sqn 5 Avn Regt while still a relatively junior officer and an inexperienced pilot. The Board was advised by several witnesses that [Australian Army Aviation] AAAvn Corps has suffered the resignation of approximately 30 QFI in the past year or 18 months. This had imposed a heavier burden on those who remained. The drain of senior pilots from 5 Avn Regt to train as QFI, in turn, reduced experience levels in the unit.
>
> **3.252.** The reason for the aircrew shortages was advised to the Board as being a combination of particularly high separation rates of [Specialist Service Officers] SSO, as well as GSO and of an inability of the recruiting and training pipelines to sustain an increased throughput to fill vacancies. The Board was advised that the limited career prospects and finite, non-extendable tenure of SSO beyond two five-year tours was the cause of the high separation rate of SSO. GSO were also reported to be in short supply due principally to employment opportunities in the commercial aviation sector.
>
> **3.253.** The Board is of the view that the shortage of aircrew (QFI and GSO in particular) may have contributed to the accident in that it led to the employment of inexperienced persons in critical positions. The board was advised that submissions had been made to alter SSO terms of employment and conditions of service. Review of such matters would appear to be an essential precursor to correction of aircrew shortages in AAAvn.

3.14 Closer Focus on Aircrew Shortages

This brief exposé of Aircrew Shortages serves to suggest that:

a. more detailed analysis into aspects such as recruiting, training, employment and separation rates might have been conducted well before this accident occurred;

b. another concept map might be drawn to provide a more detailed representation, including aspects listed in a., above;

c. recruiting, training, employment, conditions of service and separation are linked through a set of ‘business rules’ not enunciated here, for example:

(1) a change in recruiting rates will affect achievable training rates, and

(2) a change in separation rates might be made by a change in conditions of service, or a change in the attractiveness of continued Service employment.

3.15 Integrating Qualitative and Quantitative Analysis

This case study readily demonstrates how qualitative analysis can inform selection of candidates where quantitative analytical techniques might be applied. Manpower modelling of pilot and QFIs is an example. Also, there is an opportunity to develop qualitative analytical techniques, such as concept mapping, to enable quantitative analysis of causality.

Strategies for recruiting and training pilots and maintaining appropriate levels of competence could be developed with the assistance of a decision support system built around system dynamics modelling. Models might concentrate on difficult to manage aspects, such as:

a. achieving higher levels of availability of Black Hawk helicopters,

b. conflict between aircraft servicing and pilot training,

c. recruitment of pilots,

d. availability of Qualified Flying Instructors, and

e. achieving competence in flying various types of mission.

A year before the Black Hawk helicopter crash occurred, an attempt was made by a Masters research student from University College, as an Army HQ sponsored research task, to apply system dynamics modelling to assist in managing various aspects such as those listed above. This initiative failed. It was stifled through the application of organisational political pressure. This suggests the importance of having support of an executive ‘project champion’. Similar observations will be made in the context of other case studies in Chapter 4 and case applications in Chapters 8-10.

This issue here is an important one: despite effective analytical tools and expertise in their application being available, many factors militate against getting to the root cause of problems. As a result, the scope of this research was broadened to consider not only the tools and techniques and their application, but the factors militating against their use as part of an organisational change intervention or management initiative.

This issue is a distraction at this stage, but will be revisited after having established a better understanding of the tools and techniques, and their application.

3.16 State-of-the-Art in Concept Mapping

Eden and Spender (1998) provide arguably the most valuable compendium of papers on the application of concept (causal) mapping techniques. They investigate the strengths, weaknesses, opportunities and threats to using these techniques. They and Eden and Ackermann (1998) demonstrate the state-of-the art in elicitation and documentation of managerial and organisational operative knowledge, and business rules, which guide daily choices and actions. In this dissertation, it is argued that such techniques can play important roles both in detailed qualitative analysis and informing choices about when and where best to apply quantitative analysis.

Aircrew shortages should have been the subject of detailed quantitative analysis, using disciplines such as system dynamics modelling, to inform recruiting policies and other management strategies. Figures 3-8 to 3-10 considered in the context of Figure 3-6 suggest, *declining morale* was an issue and was symptomatic of, or contributed to, other deeply rooted problems. Let us expand this point by reference back to our case study.

3.17 Focus on Critical Nodes

Further to our analysis of feedback loops, analysis of nodes brings further valuable insight. Nodes are points where influences converge or diverge. Nodes have influence over concepts to which they are linked, or are influenced by linked concepts, depending on the direction of causality shown by arrows. In the case where the link is connotative, causality may change in direction: concepts appear to influence each other. With few exceptions, links may change in strength and causality over time and may depend on initial conditions. Singular, direct, linear causal relationships are the exception rather than the norm.

Some nodes are much more important than others. We need to be able to identify them, and why they are more important. Intuition suggests that counting the number of arrows in, or out, gives an indication of the importance of a node. This count is an excellent guide but cannot be used alone. The nature of each link needs to be considered. Further, when a node is common to a number of circular feedback loops, it has extraordinary influence or is influenced to a greater extent. It is to such nodes we should direct development of our management strategies.

See Figure 3-11, which depicts the situation that existed months before the crash. Some aspects were in place years before. Those loops linking *declining morale* which have already been discussed have been put into the background for the time being, to minimise distraction.

In their absence, read Concept No. 21: *loss of experience base*, noting that *loss of experience base* is a key input to Concept No. 4 *failure to inform the judgement of those responsible for designing combined arms training and associated safety [and support]* and Concept No. 36 *errors of judgement*. The latter contributed directly to the final tragic events. In order to inform development of management strategies, consider Concept 4 and those concepts linked to it, firstly those that comprise feedback structures:

a. Concepts 4 → 14 → 2 → 4: *failure to inform the judgement of those responsible for designing combined arms training and associated safety → inadequate oversight and control of this combined arms activity (CT/SRO training exercise) → failure to recognise complexity of tasks 5 Avn Regt were required to undertake to support CT/SRO and capability development → failure to inform the judgement of those responsible for designing combined arms training and associated safety.*

b. Concepts 4 → 3 → 13 -- 2 → 4: *failure to inform the judgement of those responsible for designing combined arms training and associated safety → failure to recognise importance of reporting aircraft incidents in training → lack of combined risk assessment and management procedures in training → failure to inform the judgement of those responsible for designing combined arms training and associated safety*, and

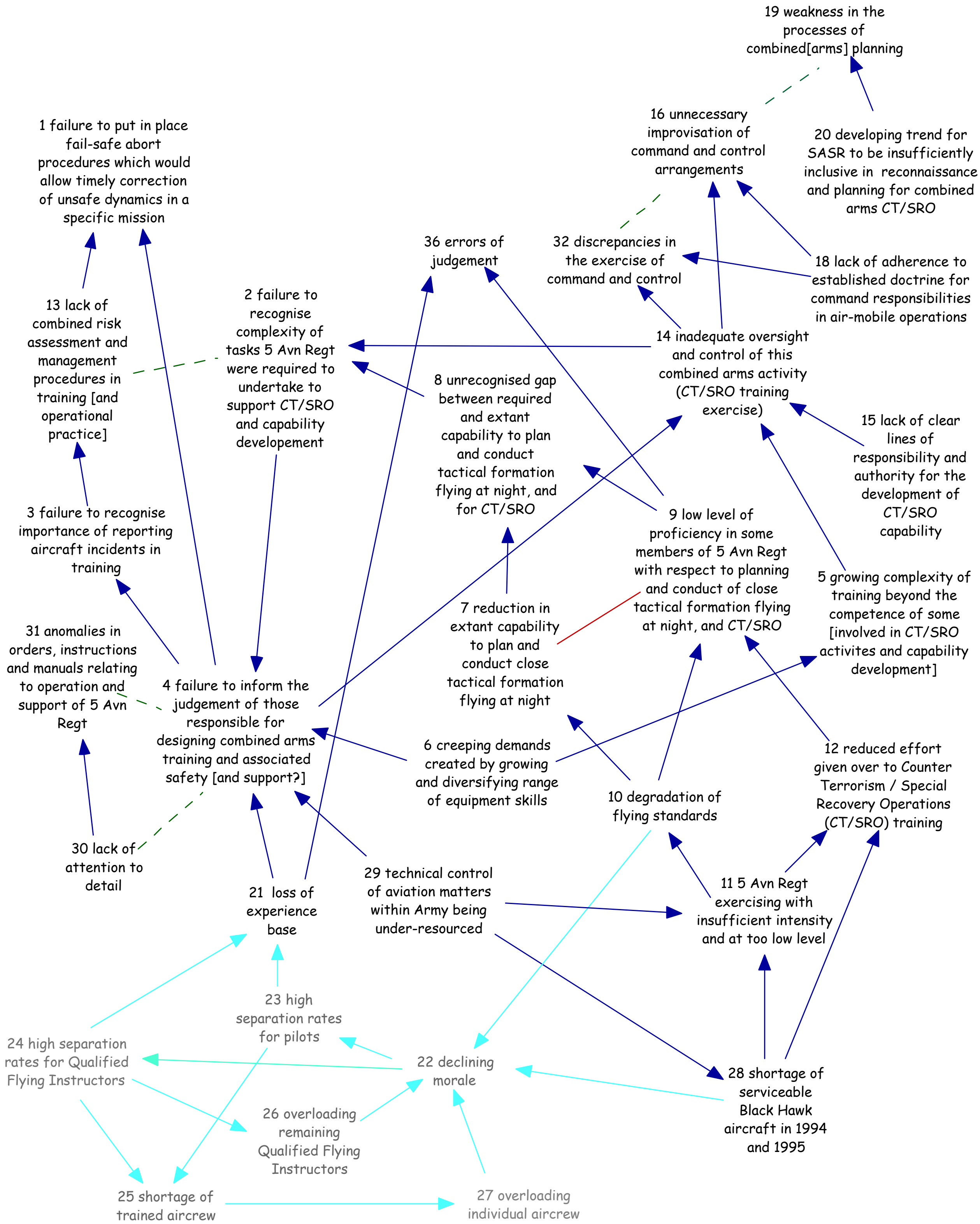


Figure 3-11. Circumstances Existing Before the Accident

d. Concepts 4 -- 30 → 31 -- 4: *failure to inform the judgement of those responsible for* *designing combined arms training and associated safety → lack of attention to detail → anomalies in orders, instructions and manuals relating to operation and support of 5 Avn Regt → failure to inform the judgement of those responsible for designing combined arms training and associated safety.*

Note should be taken of the connotative links 4 -- 30, 31 -- 4, and 13 -- 2 in the latter two feedback loops. These links are open to interpretation. They are considered to be pseudo-feedback loops because for at least part of the time their influence is in the same direction as the causal links. When this occurs, the loop is complete.

Concept No 4 has nine links. It is a critical node. Intuitive reasoning also suggests that *failure to inform the judgement of those responsible for designing combined arms training and associated safety*, is critical, even when considered in isolation.

Further, the concepts to which it is linked are important in their own right. Consider, for example, the following:

a. Concept No 2: *failure to recognise complexity of tasks 5 Avn Regt were required to undertake to support CT/SRO and capability development*;

b. Concept No 14: *inadequate oversight and controls of this combined arms activity (CT/SRO training exercise*; and

c. Concept No 1: *failure to put in place fail-safe and abort procedures which would allow timely correction of unsafe dynamics in a specific mission*.

There should be no doubt that Concept 4 is a critically important pressure point. Changing Concept No 4 or the nature of the links to or from it, that is the extent to which it affects other concepts or the influence it has, may have significant influence on the likelihood or consequence of possible outcomes. Intensively managing Concept No 4 would have been very likely to produce enduring improvements. Tackling a difficult problem is often a matter of seeing the where leverage lies.

In addition to our consideration so far, we might view concepts as sources or sinks. Those that are sources have influence on several concepts, whilst those that are sinks are influenced by several concepts. In most cases, concepts are sources and sinks at the same time.

Concepts at the boundary of the map are either sources or sinks. Sources are more likely to appear lower in the map, and sinks near or at the top. Referring back to Figure 3-7 and focusing on Concept No 28, we see it is a source with influence on three concepts, Nos 22, 11, and 12 respectively. It is also a sink with influence from Concept No 29. The fact that Concept No 28 *shortage of Blackhawk aircraft in 1994 and 1995* is an influential source is most important in this map.

Clearly, another map focusing on aircraft serviceability would give a picture of what influenced the 1994/95 shortage. But, that is outside the boundary set for the extant map. Reiterating, Concept No 28 is an influential source worthy of closer consideration. Much earlier, serviceability of Black Hawk helicopters should have been better managed, but it was not.

In the early 1990s, after considerable inter-Service bickering, Army had taken control the helicopter fleet from the Royal Australian Air Force (RAAF). RAAF had flown troop-carrying helicopters with distinction in Vietnam and was reluctant to lose this capability. RAAF also had extensive expertise maintaining helicopters. Further, the purchase of Black Hawk helicopters had been an embarrassment to the government, Minister for Defence and Chief of Defence Force (CDF). The Black Hawks had proven very expensive both to procure and to maintain, much more so than their predecessor the Bell Huey UH-1 series aircraft. Their procurement occurred almost concurrently with the hand-over from RAAF to Army. Army was faced with taking over from RAAF and bringing a new and more sophisticated aircraft into service, with all the concomitant training and logistics demands. It was little surprise to many, particularly the RAAF, that a chronic shortage of spares occurred and unserviceability became a serious problem in 1994/95. Many RAAF officers had predicted this years before.

Whilst is might seem obvious after the fact, and after the Board of Inquiry had completed its deliberations, these concepts and relationships should have been understood and managed routinely. It is suggested that had this been so, the accident might have been averted.

Indeed, it is suggested that any strategy to avoid training incidents or accidents in the future would be directed at correcting critical Concepts such as those identified by our analysis here. The Board of Inquiry's observation that *failure to inform the judgement of those responsible for designing combined arms training and associated safety …* suggests the worst failure, the failure to learn. In general, failure to understand and to learn leads to a breakdown in the management of risks.

Before leaving this point, it is most important to note that effective approaches designed to fix problems should be multi-pronged. Problems should be attacked simultaneously at strategic, operational, and tactical levels.

At the strategic level, those concepts most worthy of attention are:

a. Concept No 4: *failure to inform the judgement of those responsible for designing combined arms training and associated safety*;

b. Concept No 2: *failure to recognise complexity of tasks 5 Avn Regt were required to undertake to support CT/SRO and capability development*;

c. Concept No 14: *inadequate oversight and control of this combined arms activity (CT/SRO training exercise)*; and

d. Concept No 1: *failure to put in place fail-safe and abort procedures which would allow timely correction of unsafe dynamics in a specific mission.*

Whether Concepts No 3, 6 and 21 also directly linked, should be included is a matter for risk assessment. See 11.1.

At the operational level, Concept No 22, *declining morale*, certainly would be worthy of attention. Figure 3-6 does not really cover tactical issues. To identify appropriate tactical level issues would require more detailed investigation and analysis.

Identification of critical issues and their continual review are fundamental risk management activities. It is not at all surprising that the Board of Inquiry's first recommendation attends to the matter of risk analysis, and subsequent recommendations relate to treatment of identified risks.

3.18 Breakdown in Management of Risks

Before the Black Hawk helicopter crash occurred, there was a breakdown in the understanding of complexity involved, failure to learn, and a breakdown in risk management. The primary interest in this research is on breakdowns linked to:

a. misunderstandings of risks, their likelihood and consequences;

b. a lack of appreciation of mechanisms and systemic structures, feedback and delay, that underlie dynamic complexity, and contribute to generation of risk;

and

c. systems-of-process, systems-of-meaning, and systems-of-knowledge-power (Flood, 1999) issues which militate against effective risk management.

The role of risk management in the management of wicked problems will be discussed further at Chapter 6. Further to sub-paragraph c., there is an assumption here that desire, ability, and scope to manage actually exists. That is, they have not been stifled. Organisational cultural issues and a ‘can do’ mentality often militate against appropriate management, and exercise of executive responsibilities

3.19 Summary – Chapter 3

Using the medium of a real-life accident case study, this Chapter sought to reveal the nature of complex, systemic problems and why they create so much difficulty for managers and decision-makers. One clear justification for this research is the savings in human lives and money that might result from development of more effective management of systemic problems.

Through the example of the case study, this chapter has demonstrated how concept mapping can be used to reveal systemic structures, how concepts are strongly coupled and how complex interrelationships can cloud managers’ vision. The importance of stakeholder perspective and organisational politics and culture were also revealed. The inability of key stakeholders to recognise evolving systemic patterns of events led to failures in understanding, learning and management of risks. Armed with this appreciation of complex problems, we are equipped to widen our search.

In the next chapter, detailed analysis is undertaken of a number of other accident case studies with the intent of determining whether there are common threads. The results are then examined to see how this information might be used both to help us understand how to identify and assess risks with the goal of managing them more effectively.

3.20 Significant Contributions Made in Chapter 3

In this chapter, the application of concept mapping is extended to the detailed analysis of a wicked problem. By application to analysis of an accident case, mapping is used to reveal ‘after-the-fact’, the nature of complex interrelationships involved. Further, this mapping is used to:

a. Demonstrate how perspectives on specific aspects of a situation can be created by selectively masking concepts that are not of primary interest – Figure 3-11;

b. Depict overall problem structure by eliminating the normal textural descriptions of concepts, so highlighting – Figure 3-7:

   (1) feedback mechanisms;

   (2) feedback mechanisms that operate only under certain circumstances; and

   (3) relationship between the most influential, or most influenced, concepts.

c. Depict which parts of the systemic structure managers might have reasonably seen had they been aware – Figure 3.11.

The new technique of 'winding back the clock', as in Figure 3-11, is a powerful way of comparing pre-event and post-event circumstances and systemic structures. This is developed in later chapters as a technique for highlighting cues that managers, decision-makers and analysts might recognise and act upon in the process of addressing wicked problems.

These contributions are intended to lead managers and decision-makers to identify 'before-the-fact', those evolving situations which, without careful management, could otherwise develop into problem situations. Without wishing to enter into the qualitative *versus* quantitative debate at this point, the significance of the analysis undertaken in this chapter is that it leads to much clearer understanding of the problem or problems being faced. In turn, this understanding becomes the foundation for risk assessments.

CHAPTER 4: CASE STUDY – DEATH OF KATIE BENDER AND OTHER 'ACCIDENTS'

Synopsis

The procedure described in preceding chapters is applied to a number of other accident cases with the aim of identifying similarities in their nature. The main case studied involves a detailed review of the Coroner's Inquest Report into the death of a spectator, a young girl, who had gone with her family and thousands of residents of Canberra, Australian Capital Territory, to witness the much publicised demolition by implosion of an old hospital building. Other cases studied include a fire in the engine room of HMAS WESTRALIA which claimed the lives of four sailors, explosion and fire at Esso's Longford, Victoria, Gas Plant No. 1 which killed two workers and injured eight others, and an explosion in a coal mine at Moura, Queensland, which claimed the lives of 11 men.

To reveal how precursor events evolved, the technique of creating a complete mapping of the relevant factors then removing those that did not exist after a certain point in time, as described in Chapter 3, was used. This provided an opportunity to see what existed when the clock was wound back to an earlier time. The precursor events and systemic structures so revealed permitted the making of a number of pertinent observations about the nature of complex, systemic problems. This knowledge will aid our recognition of complex problems, our understanding of their nature, and help improve the selection of tools and analytical techniques we might employ. The aim is to improve the likelihood that any analysis we undertake focuses on core issues, where we might make a small change that will make a big difference. A concept map of Chapter 4 is at Figure 4-1.

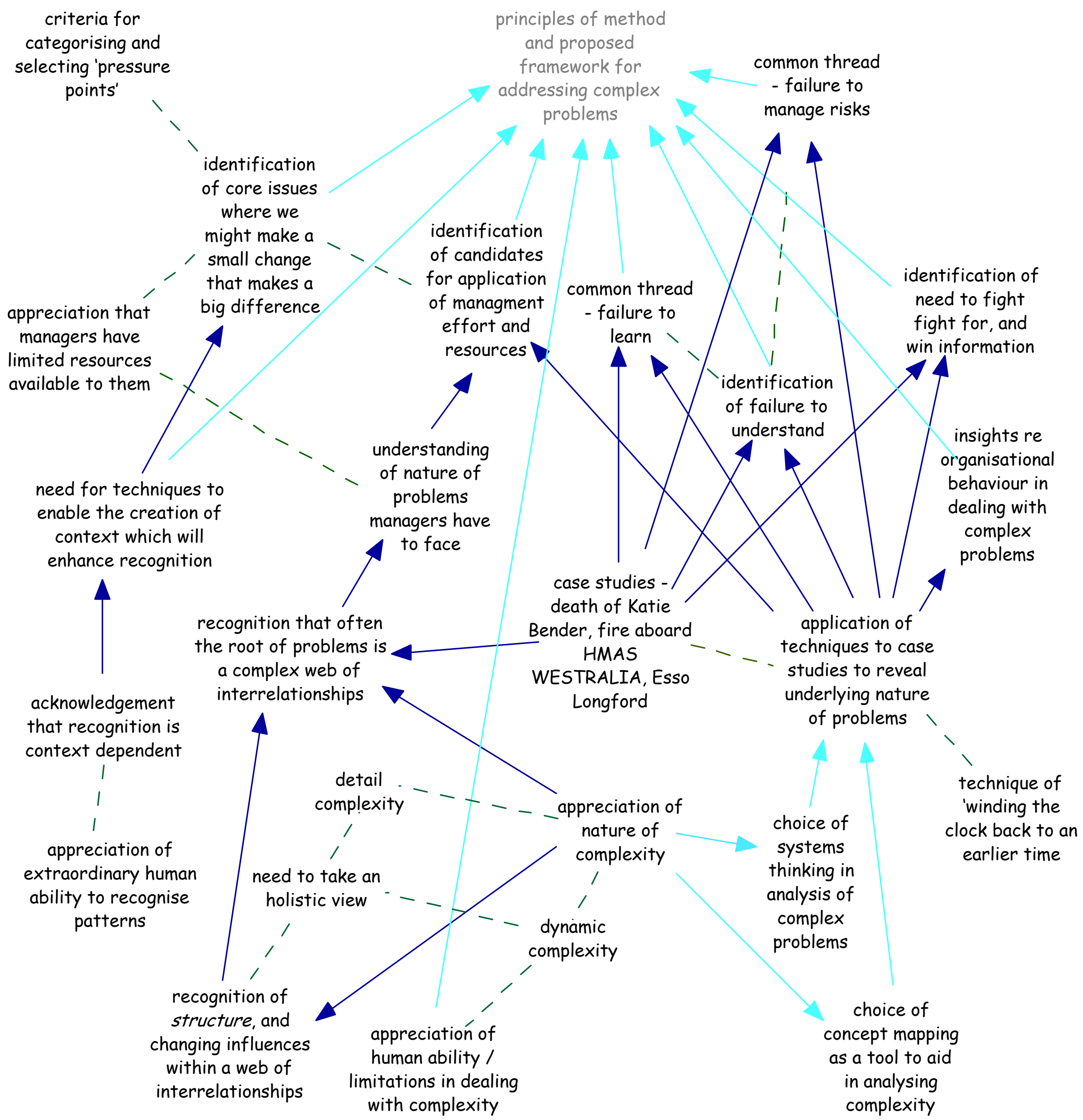


Figure 4-1. Concept Map - Chapter 4 (1)

Note:

1. Concepts shown in black text are contained in this chapter.

4.1 Analysis of the Coroner's Inquest Report Regarding the Death of Katie Bender

The procedure of the previous chapter was applied firstly to the Coroner's Inquest Report regarding the death of Katie Bender. Full details of that case study are included here. Only summaries of results from other case studies are included. Concept maps were drawn by hand to demonstrate that sophisticated decision analysis software is not essential. Thirty-three such maps depict the relevant information distilled from the 657-page Coroner's Report. The full set has been scanned and can be found on the enclosed CD-ROM. Selected maps of particular interest are reproduced here. They are:

a. Settling on implosion as method of demolition, Figure 4-2.

b. Adequacy of tender selection process, Figure 4-3.

c. Demolition Code of Practice, Figure 4-4.

To handle the numbers of concepts and the complex interrelationships involved, it became necessary to use computer support. Banxia® *Decision Explorer* is an application developed by Eden and Ackermann at Strathclyde University, Glasgow, and Banxia for this purpose.

Some rationalisation of concepts was needed to:

a. reduce the total number of concepts to a manageable level, and

b. provide a uniform level of aggregation across each of the thirty-three maps.

This permitted amalgamation into a single map containing just over 200 concepts. This 200-concept map was analysed using functions provided by the *Decision Explorer* software. As indicated earlier, an alternate and practical way of constructing large concept maps is to use a whiteboard, bigger the better, and Post-it® Notes. A single concept is written on an individual Post-it® Note. These are clustered together with like concepts. Arrows are drawn between them to depict causal, connotative and conflicting links. Eden and Ackermann do this with oval-shaped stickies using what they refer to as the *Oval Mapping Technique* (Eden and Ackerman, 1998: 303-320).

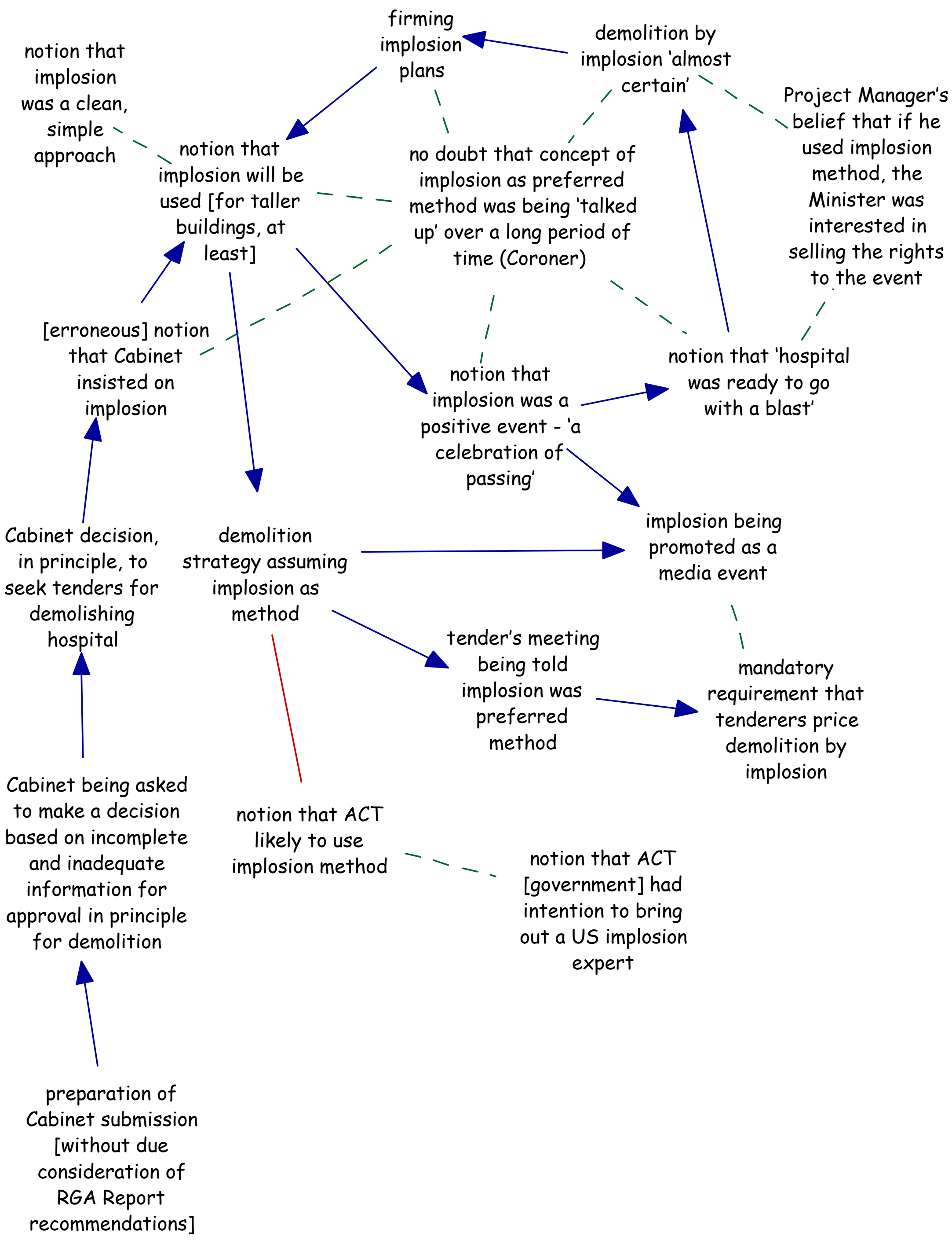


Figure 4-2 Settling on Implosion as Method of Demolition (1)

Notes:

1. That the concept of implosion as the preferred method was talked up over a long period of time, is an example of groupthink. For a detailed explanation of groupthink, see Forsyth (1983: 490) and Silverstone (1993).

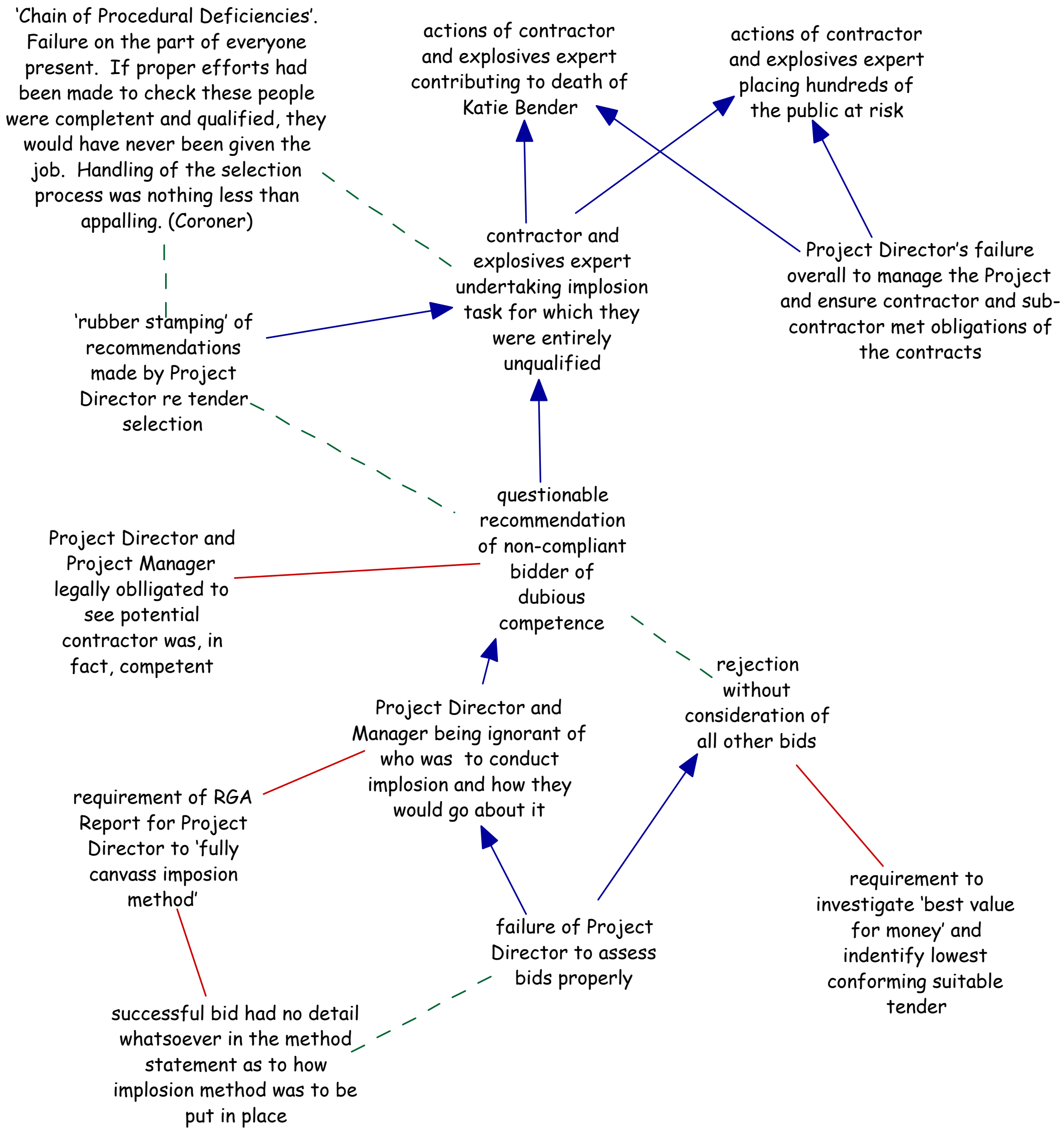


Figure 4-3 Adequacy of Tender Selection Process

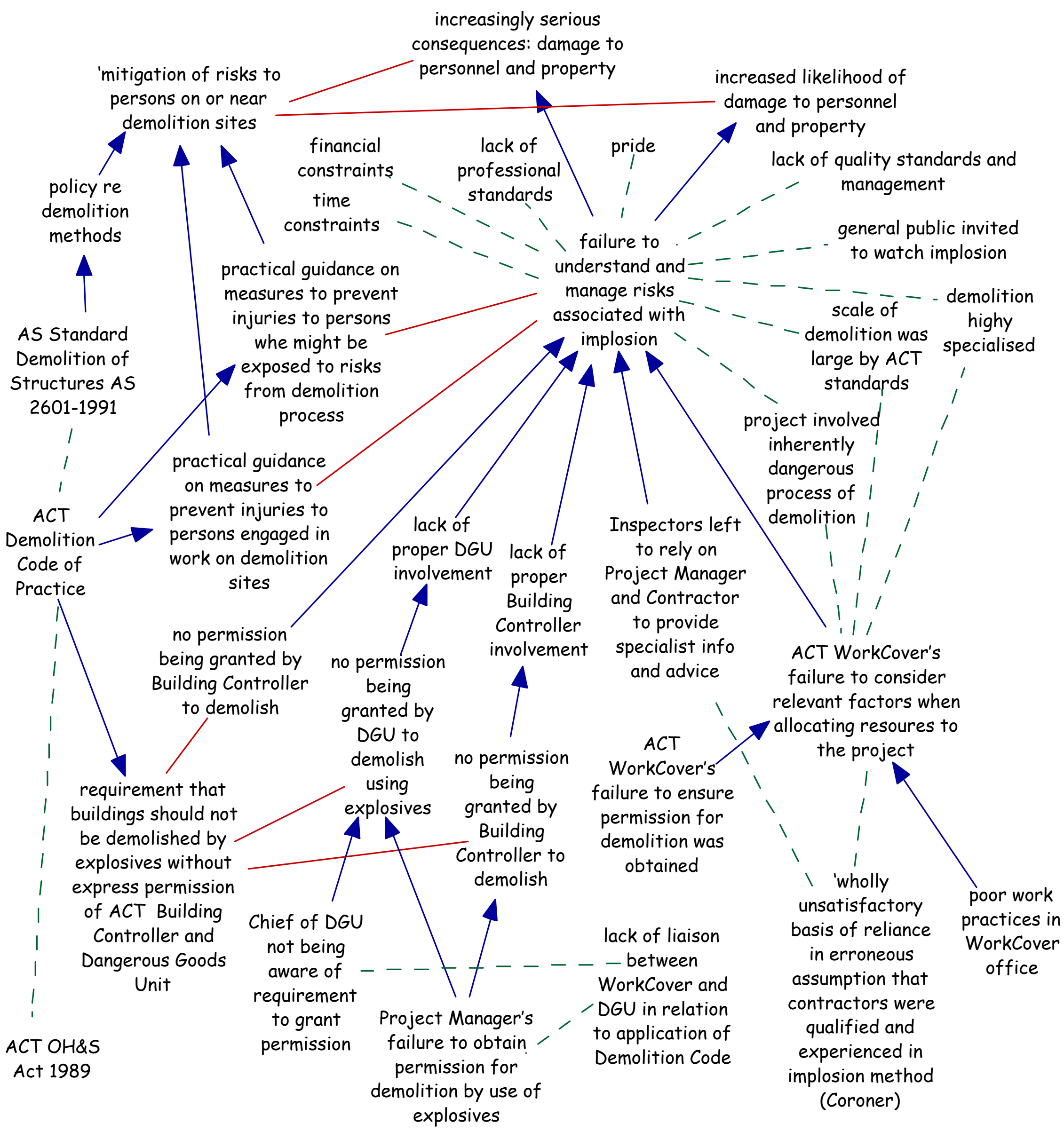


Figure 4-4. Demolition Code of Practice

4.2 Choosing and Working at the Appropriate Level of Aggregation

Choosing and working at the appropriate level of aggregation is important. Typically 200-400 relevant concepts may be identified in complex problems. This was so in the cases studied. Such large numbers of concepts are almost unmanageable. As the numbers of concepts goes up, so the practicality and intelligibility of the map reduces, becoming obscured by the massive amount of detail. It is impractical to work routinely at this very detailed level.

The upper limit, even using tools such as *Decision Explorer* is around 200 concepts. The practical size of concepts maps and the meaning of information derived from maps will be discussed again later. For the purpose of the type of analysis being conducted here, 200 concepts is considered to be the practical upper limit.

When in a workshop setting, the following can dictate the need to work at a higher level of aggregation:

a. Time to access those with knowledge and experience in the problem space.

b. Effort involved in the compilation of maps.

c. Effort needed to complete the validation of maps.

Groups working together at higher levels of aggregation, are generally comfortable with maps containing 30-70 concepts. Eden and Ackermann (1998) make the same observation.

4.3 Settling on Implosion as Method of Demolition

In Figure 4-2, it is clear that there is a cycle reinforcing the notion of imploding the hospital. What is not clear is where this started. This is what Beer describes as the *Method of Tenacity*, after American philosopher Charles Peirce (Beer, 1966). *Method of Tenacity* is a term used to describe a mechanism by which ideas can originate then become cemented in the belief systems of individuals and groups, even though the original idea may be fantasy, exaggeration, or a significant distortion of the facts.

4.4 Demolition Code of Practice

In the Figure 4-4:

a. There was a Code of Practice although not written for implosion in the first instance, it catered for demolition by implosion.

b. There was a failure to understand and manage risks associated with implosion. This ‘failure’ concept was identified by our analysis as the most influential node.

c. There were influences not considered by many to be important, but were:

   (1) Pride which precluded any individual taking unilateral action to stop the demolition, even though this was within the power of many to do so.

   (2) Artificial time constraints which created pressure on individuals to take shortcuts.

This map, in particular, shows a litany of failures, oversights, aversion to getting involved, failure to follow procedures, shoddy practices, and incompetence.

4.5 Winding the Clock Back to an Earlier Time

Winding the clock back to an earlier time involves:

a. Identifying a point in time, or a specific event, of interest.

b. Without rearranging the structure of the completed map, systematically removing those links and concepts that occurred, or existed, after the selected time or event.

c. Comparing the structure of the original map with that depicting the situation that existed at the point in time to which the clock is wound back.

The characteristic systemic structure of this problem was clearly visible at the time before the fence was erected around the demolition site. All that was needed to enable such a revelation was for someone in a position of authority to take a holistic view, a helicopter view, *weltanschauung* looking at the *systemicity*, of what existed at the time. Characteristic problems and systemic structures existed before the first brick was broken or the first steel beam was cut, and more than a year before the first explosive charge was laid. It is highly significant that the structure of the final, complete map is so similar to the map that could have been derived from what was reasonably known at the time the contracts were signed (about the time the fence was erected around the site). The systemic structures which would lead to the ultimate catastrophe were in place even then.

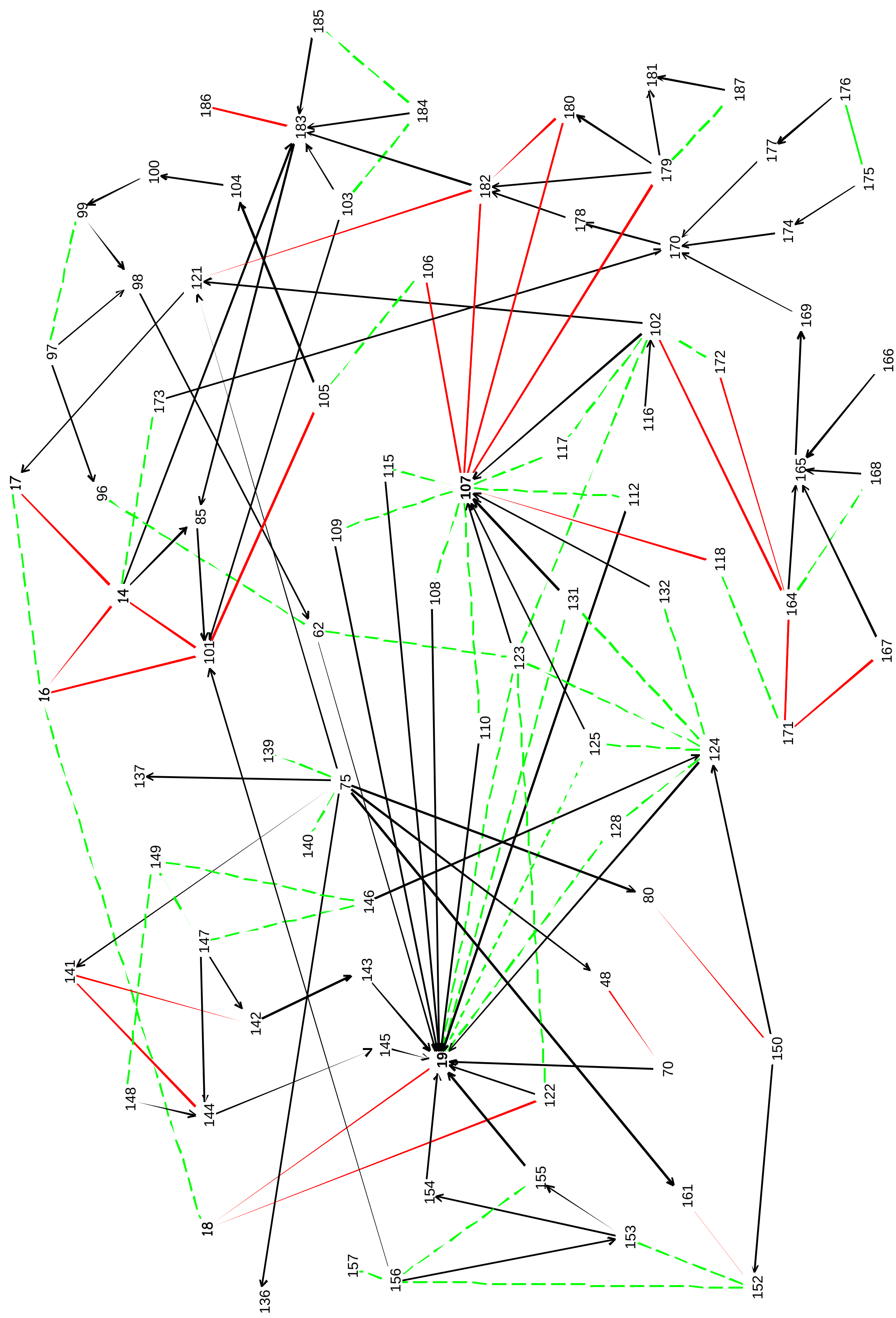


Figure 4-5 Systemic Structure Existing Many Months Before the Demolition

This analysis serves to reinforce Coroner Madden's general conclusion that a reasonable person having been furnished with information about what was reasonably known at the time, would have come to the realisation that a dangerous situation was developing. Indeed, the 'winding back the clock' technique suggests a reasonable person should have been concerned about development of a potentially dangerous situation many months before Katie Bender died from injuries sustained when struck by debris from the demolition site. It is now history that nobody recognised this, or if they did they did nothing.

The most influential active node, in place many months before the accident was … *failure to understand and manage risks associated with implosion.* See Figure 4-5.

Winding back the clock in the Black Hawk case produces similar findings: much of the systemic structure of the problems was already set in place. *Failure to understand, to learn and, hence, to manage risks* was also dominant. See Concepts No 2 and No 4 in Figure 4-6. This suggests the key to avoiding systemic problems lies in recognising the developing patterns, noting that the patterns do <u>not</u> suddenly appear. How to facilitate such pattern recognition should be an objective of any intervention or decision-support methodology we might design.

4.6 Significance of the Completed Map

The complete picture, the map of the Coroner's Report could only be known after the Coroner had completed his deliberations of the evidence contained in the 10,000 pages of transcript. See Figure 4-6. However, a reasonable person could have reasonably known the circumstances and, hence, the systemic structures that existed at, or about, the time the contracts were signed. This is when effective management effort could have been, or should have been, applied. But it was not. Similarly, in the Black Hawk case, there was denial and inaction. The challenge lies in bringing available information together in a form which enables recognition of developing patterns so informing risk analysis, decision-making and strategy development. This is part of knowledge management.

4.7 Identifying Candidates for Quantitative Modelling

In the Katie Bender case, the concept mapping analysis did not reveal opportunities for system dynamics modelling. It certainly helped identify where blast effects modelling

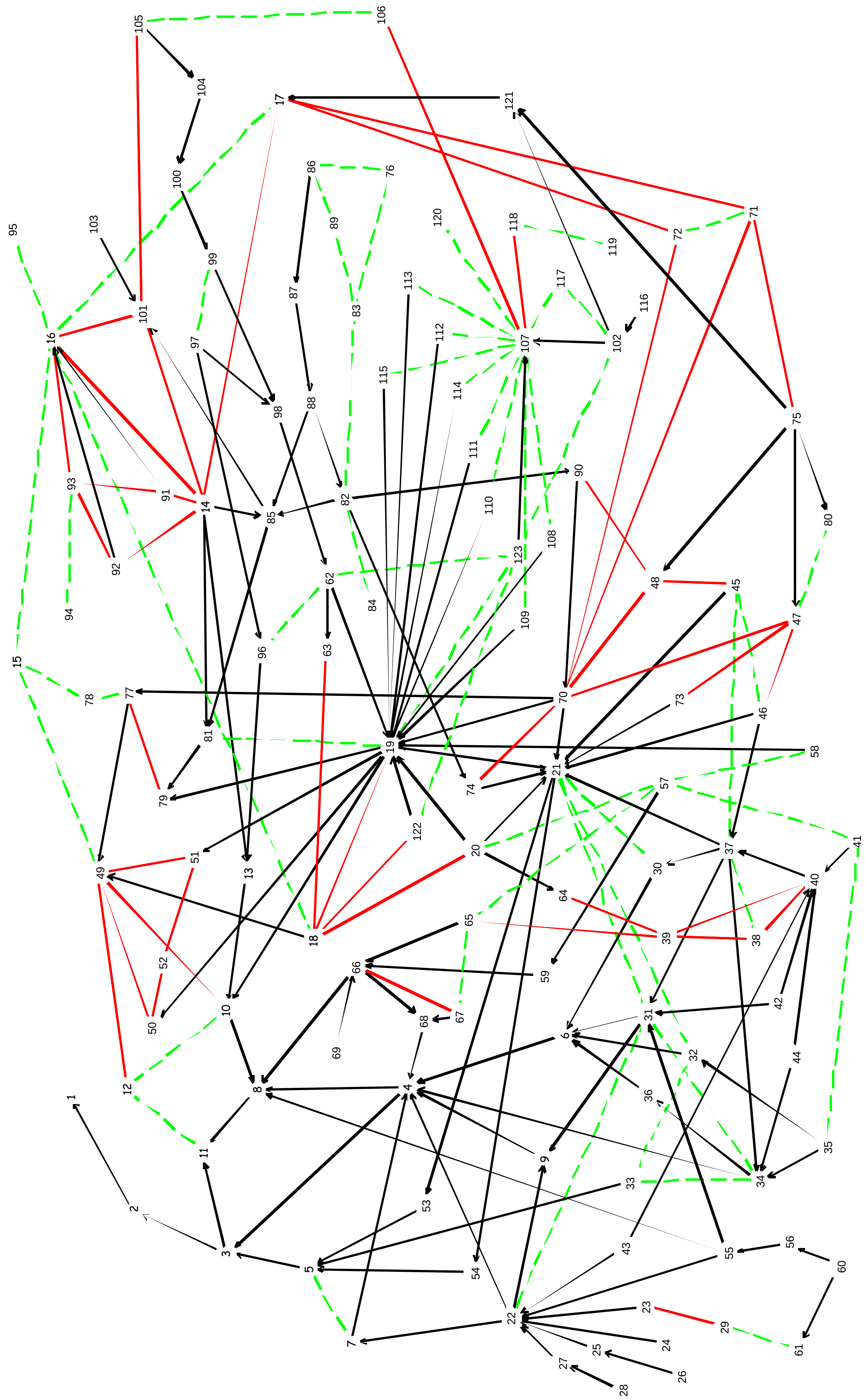


Figure 4-6. Systemic Structure at Time of Implosion

might have been applied to predict the likely outcomes of the proposed implosion methodology. However, even without anything as sophisticated as forensic modelling of any type, it is now obvious, in these cases, where management effort should have been applied. That, in itself, is an important research finding.

4.8 Value of Mapping

These concept maps can be likened to those of large cities, where there is a central business district (CBD) with numerous arterial links. An industrial area and suburban shopping centres, major and minor nodes, are readily identifiable. Major routes can be seen linking them. One map could be Sydney, another London, and yet another San Francisco. The same sort of topology exists. It is not necessary to go through each of these case studies in minute detail to identify the CBD, industrial areas, shopping centres and routes between them. A CBD is readily recognisable: you don't need the detail of every building in the CBD to recognise that it is the CBD. Much of the detail can be removed from the map and the general topology, the structure of the problem, remains.

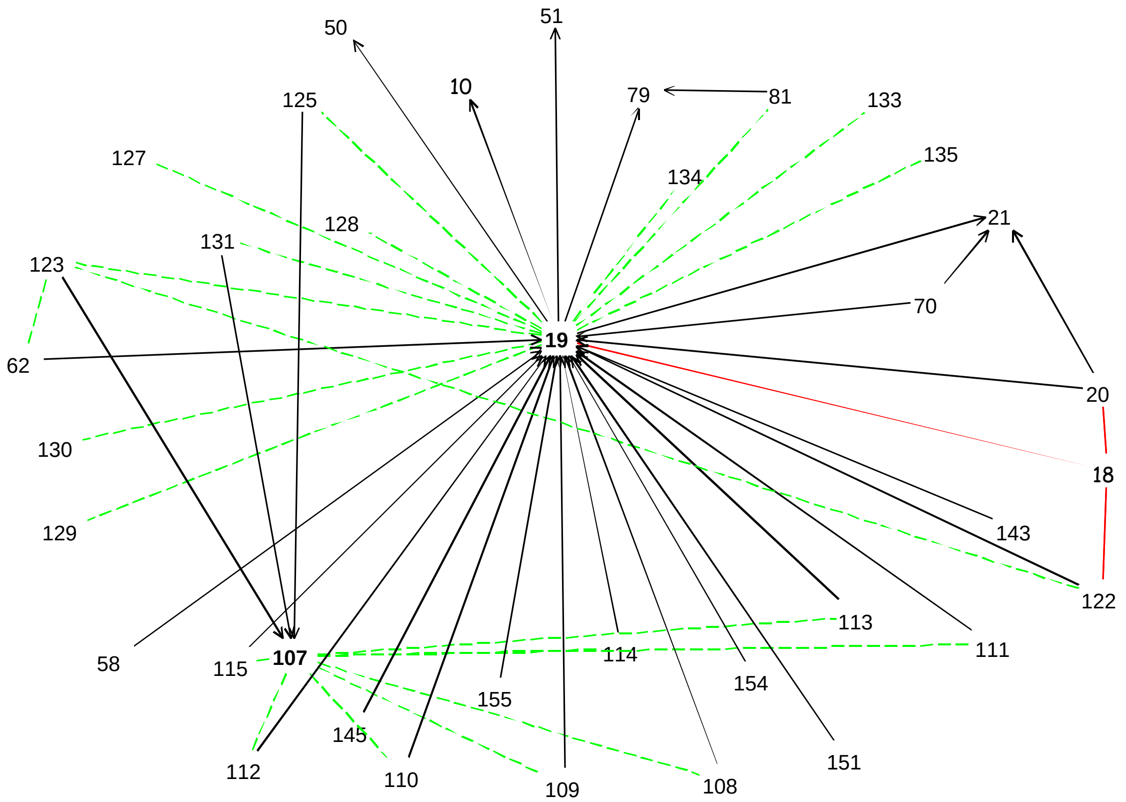


Figure 4-7 Context Diagram Focusing on Concept No. 19 – Failure to Learn (1)

Notes:

1. The purpose of this diagram is similar to context diagrams used in systems

> engineering. That is, it focuses on a central concept to gauge its influence, or how critical it is.

In each of these cases there are a bunch of clearly identifiable and highly important nodes, pressure points or leverage points that might need intensive management.

In the Katie Bender case, see Figures 4-5, 4-6, and 4-7 there are two prominent nodes:

a. Concept No. 107 refers to the Report by R.G. Glenn and Associates – *Expression of caution about matters that ought to be thoroughly investigated before implosion was used*, and

b. Concept No. 19 - *Failure by those involved to understand and manage risks associated with demolition [by implosion]*

The Report by R.G. Glenn and Associates (RGA) outlines a series of concerns about the method of demolition. It advises that if implosion is chosen as the method of demolition there are risks to be considered and required for further investigation, before demolition commenced. In the case of implosion being chosen RGA advised against implosion at times when spectators might be around and placed at risk. The RGA Report clearly warned against public exposure to risks associated with the demolition.

The cautions expressed in the RGA Report were ignored. It is doubtful that anybody in a position of responsibility read the RGA report. The recommendations of the Report were not brought to the attention of Cabinet when a decision was to be made regarding proceeding with the demolition.

The Coroner found a litany of systemic failures at all levels, from the Chief Minister down. Failure to read, appreciate and implement recommendations of the RGA Report is an example. The Coroner also found many examples of incompetence. Incompetence was an element in the other cases studied, but none so prominently as in the Katie Bender case.

4.9 Common Threads

At Longford, there was considerable tension and mistrust between plant operators and management. Operators believed they were being lied to by management despite the fact that, just months before, Esso's parent company Exxon had conducted a safety audit and given the Longford plant a clean bill of health. An explosion and fire killed two men and disrupted the gas supplies to the State of Victoria for weeks. Hopkins (2000) comments on lessons that should have been learnt before Longford:

> The failure of audits to identify problems revealed in post-disaster inquiries is unfortunately commonplace. Following the fire on the Piper Alpha oil platform in the North Sea in 1987, in which 167 men died, the official inquiry found numerous defects in the safety management system which had not been picked up in company auditing. There had been plenty of auditing, but as Appleton (1994) one of the assessors on the inquiry, said "it was not the right quality as otherwise it would have picked up beforehand many of the deficiencies which emerged in the inquiry." In fact audits on Piper Alpha regularly conveyed the message to senior management that all was well. In a widely available video of a lecture on the Piper Alpha disaster, Appleton makes the following comment:
>
> > When we asked senior management why they didn't know about the many failings uncovered by the inquiry, one of them said: "I knew everything was all right because I never got any reports of things being wrong." In my experience, … there is always news on safety and some of it will be bad news.
> >
> > *Continuous good news – you worry!*
>
> Appleton's comment is a restatement of the well known problem that bad news does not travel easily up the corporate hierarchy.

As problems grow warning signs amongst people may appear as frustration, tension, uncertainty or anger. In business dynamics, symptoms of underlying problems appear as instability, cycles of 'boom and bust' (Paich and Sterman, 1993) and counter-intuitive response of business problems to corrective action. The normal management strategy is to direct corrective action toward the symptoms.

Corrective actions are frequently applied with little real understanding of the root causes. Too frequently, strategies are directed at correcting a handful of seemingly disparate symptoms when, in reality, those symptoms are tightly coupled. One obvious reason is that root causes themselves are rarely obvious.

Instead of accepting that they might have to grapple with a tangled web of factors, people generally look for simple, single direct causes for problems they face. Meadows (1989) observes that this creates further problems:

> Here are a few of the common assumptions of the current industrial paradigm …

clearly unsystematic and problematic:

> … one cause produces one effect … there must be a single cause of acid rain or cancer or the greenhouse effect, and we just need to discover and remove it
>
> … relationships are linear, nondelayed, and continuous; there are no critical thresholds, feedback is accurate and timely; systems are manageable through first-order negative-feedback-loop thinking
>
> … a problem does not exist or is not serious until it can be measured. (Meadows, 1989: 70-71).

In the Black Hawk helicopter case, declining morale may have been attributed to a single obvious cause by those involved, at 5th Aviation Regiment, or by Army's personnel managers. This is not clear from the Board of Inquiry's report. If declining morale and other warning signs had been recognised and their implications better understood, as suggested by the concept mapping analysis in Chapter 2, it is very likely this might have triggered corrective action and contributed to reducing the opportunity for tragedy to occur.

During the refit of HMAS WESTRALIA concerns, among some involved in the work, that there was no competent authority closely managing the configuration of the ship were ignored. Fuel lines of the unapproved type would not have been fitted under normal, controlled circumstances. There was a lack of control and reporting, and there was no prior experience with flexible fuel lines in this type of application.

That the WESTRALIA's sister ship, RFA BAYLEAF, had suffered a similar, but less serious, engine room fire six months earlier was seemingly ignored. Whilst the same type of flexible fuel lines had not been fitted to RFA BAYLEAF, and so were not a contributory factor, lessons could have been learnt from that fire. For example, lessons could have been learnt about the difficulties of fighting a fire in such a cavernous space as the engine-rooms this class of ships have (Dept of Defence, 1998). They were not.

This concept mapping and systems thinking analytical approach allows us to identify those concepts that are critical under 'normal' circumstances. Critical concepts, in the cases described in this chapter, were:

a. Black Hawk helicopter crash - *failure to inform judgement of those responsible for designing combined arms training and associated safety [and* *support?]*, see Figure 4-6.

b. Death of Katie Bender - *failure to understand, failure to learn, and failure to manage risks*. See Figures 4-5 and 4-6.

c. Fire aboard HMAS WESTRALIA - *failure to understand, failure to learn, and failure to manage risks.* The Naval Board of Inquiry found that there was no competent authority either within the Royal Australian Navy or the Project Manager, Australian Defence Industries, which critically examined the wisdom of the intended course of action [to fit flexible fuel pipes of an unapproved type which subsequently ruptured causing fuel to be sprayed onto parts of the hot engine] (Dept of Defence, 1998).

d. Longford explosion and fire - *failure to understand, failure to learn, and failure to manage risks.*

e. Moura Mine Disaster – *failure to understand, failure to learn, and failure to manage risks.* In this case, failures in communications between workers on different shifts, between workers and those responsible for managing safety were also identified as critical contributions (Hopkins, 1999).

The common thread might be expressed as *failure to understand the complexity being faced, failure to learn and, hence, failure to manage risks*.

4.10 Major Risk Key Performance Indicators

In the cases studied, in this and the previous chapter, a number of cues were identified ‘after-the-fact’. Coroner Shane Madden makes the argument that a reasonable person, presented with what was reasonably known (or could have been reasonably found out with a bit of investigation), that is, a reasonable person presented with these cues, should have been concerned about problems that continued to develop unabated. Madden’s argument is a compelling one. The cues mentioned were indicators of the health of the system. They signified that problems were growing, and that a reasonable person should have been worried about what they saw.

To make use of this as a management tool requires ‘before-the-fact’ identification of the cues and recognition of potential consequences, then routinely managing the problems these cues suggest might be growing. This, of course, is the intent of risk management, noting that in these cases risk management failed because the cues were either not recognised or were ignored.

Risk Management Issue / Key Performance Indicator	Actual Consequences / Comments
Serviceability of aircraft.	Shortage of serviceable aircraft in 1994 and 1995 (Concept 28, Figure 3-6) contributed to: • Reduced opportunity for pilots to gain experience in CT/SRO operations. • Declining morale among pilots and QFIs. • 5 Avn Regt exercising with insufficient intensity and at too low level.
Pilot / QFI availability and current level of completence.	Declining morale (Concept 22, Figure 3-6) contributed to: • High separation rates among pilots and QFIs. • Shortage of trained crews. • Overloading of individual aircrew. • Subsequent loss of experience base.
Occurrence of technical control 'incidents'.	Technical control of aviation matters within Army being under-resourced (Concept 29, Figure 3-6) contributed to: • Shortage of serviceable aircraft in 1994 and 1995. • 5 Avn Regt exercising with insufficient intensity and at too low level. • Failure to inform judgement of those responsible for designing combined arms training and associated safety [and support].
Frequency of aircraft incidents in training.	Insensitivity to reported aircraft incidents led to failures in design of training (Concept 4, Figure 3-6), which contributed to • Inadequate oversight and control of combined arms activity (CT/SRO training exercise). • Failure to put fail-safe procedures in place. • Failure to recognise importance of training incidents involving aircraft.
Oversight and control of combined arms CT/SRO training.	Inadequate oversight and control of CT/SRO combined arms training activities (Concept 14, Figure 3-6), which contributed to: • Failure to recognise complexity of tasks 5 Avn Regt were required to undertake to support CT/SRO and capability development. • Discrepancies in Command and Control

Table 4-1 Major Risk Key Performance Indicators – Black Hawk

Key performance indicators, indicators of risk management issues, which might have been established for routine management of Black Hawk helicopter training operations, are summarised in Table 4-1. Whilst the *Actual Consequences*, in the right-hand column, could not have been known, routine risk assessments should have resulted in compilation of educated assessments and forecasts of likelihood and consequence. Risk management processes are described in detail in Australian / New Zealand Standard (AS/NZS 4360: 1995). This should have been part of routine risk management. That routine risk management failed, failed in its implementation, or failed or organisational, political, or other reasons, is profoundly important. In this dissertation, an attempt is made to identify ways of correcting such failures through appropriate use of qualitative and / or quantitative analytical techniques.

4.11 Aversion to Dealing with Excessively Complex Issues

In the decision-making process, in management, there is a gap, or disjoint, between those who make the decisions and those who are required to advise, analyse, or implement. Executive decision-makers would prefer, for a variety of reasons, to distance themselves from the mess of detail and dynamics of complex problems. This creates barriers to learning and effective decision-making. See 2.25.

4.12 Observations About the Use of Concept Mapping as an Analytical Tool

Maps of individual case studies can contain 200-300 concepts. Detailing with this amount of detail is not recommended as part of a normal consultancy activity. It is too slow and cumbersome. It is only feasible in a research setting. The approach described in this thesis has been necessary to reveal the nature of those problems being addressed. When using any from of directed graph, selecting the appropriate level of aggregation is important. This is a matter of skill and experience. Coyle (1996) and Coyle and Exelby (2000) describe a ‘Cone of Influence Diagrams’ within which diagrams drawn at higher or levels of aggregation fit. The idea of reducing the level of complexity being described to a point where clarification becomes possible is an overall purpose in diagramming (Craig, 2000).

Clarification follows recognition and recognition is context dependent. So, to ensure we create enhanced opportunities for executive decision-makers to recognise patterns of behaviour we have to create the right context (Richardson and Pugh, 1981; Carroll and Johnson, 1990; Klein et al, 1993; Klein, 1998; Gigerenzer et al, 1999). Consequently, consultancy practice must include focusing attention on setting and developing the context. Facilitating 'situation awareness' (Klein, 1998) is critically dependent on recognition. See 2.19. It is also an essential precursor to understanding, understanding which must be developed before we can develop workable management strategies.

4.13 Critical Review of Mapping Applied to Case Study Analysis - Questions and Answers

The findings of this research, specifically relating to the accident cases, were presented at two seminars:

a. At the University College, University of New South Wales, in 28 April 2000. This was a formal presentation of PhD research to date. It was attended by:

   (1) Head of School of Civil Engineering

   (2) Academic co-supervisor (supervisor was unable to attend)

   (3) Representatives from Defence Science and Technology Organisation, Institution of Engineers (Australia), Systems Engineering Society, Defence Acquisition Organisation systems engineering staff.

b. 'Lessons From Disasters' Seminar - Newcastle Division of the Institution of Engineers, 20 June 2000. This was attended by some 100 professional engineers (IE Aust, 2000).

The following summarises questions asked at those seminars:

4.14 Veracity of Research Results

Q. Information in the various Reports can be challenged. How does this affect the conclusions and the findings of the research?

A. Aspects of the results could be put in doubt, to some extent. However, because our focus is in the critical, most influential nodes and the systemic structure, removing or negating some concepts or links has only marginal effect. Those structures or nodes identified as critical remain critical even if a significant number of elements of information are challenged. The research does not rely on one or two pieces of information. So, the general findings remain unaffected.

The main risk to application of the method is in failure to be objective. This failure could result in the building of maps representing what the person building the map hoped the author might be saying rather than what that author actually said or wrote. The mapper cannot let his own views or biases to be built into the maps. One technique for minimising bias is to present the complete, or partially complete, map back to the author for validation. This is consistent with an action research / action learning approach (Revans, 1982).

The knowledge elicitation technique used during empirical case study research (described in the later chapters) involved a two-staged interview process:

a. During the initial interview, a series of questions were posed to the interviewee. The interview was recorded. During the interview, concepts were noted and linked as far as possible. This led to the building of a set of partially complete maps. After the interview, a transcript was prepared from the recording. The transcript provided the additional information needed to build complete maps of what was discussed during the interview. Occasionally maps were found to be mildly confused, illogical or incomplete. Sometimes, there were omissions from logical arguments. This was due, in part, to lack of clarity of expression on the part of the interviewee. It was also due to errors of interpretation by the interviewer during the subsequent mapping.

b. When the maps were presented back to the interviewee at a subsequent meeting, the interviewee was briefed on what the map portrayed. The interviewee was encouraged to ask questions regarding the map, as it was presented, and to make corrections. Up to this point, the scope was limited to the original focus of the initial interview. Only when all corrections were made, was the interviewee asked if he had any afterthoughts that might be included as additions to the map.

In this type of research, particular attention must be paid to:

a. <u>Inter-coder reliability</u>. Identifying concepts from documents, requires skill in parsing, a good understanding of the written language and an awareness of difficulties introduced by linguistics. Threats to inter-coder reliability, the fidelity of the reader identifying exactly what the writer intended, are ever-present in such tasks. The level of inter-coder reliability achieved here could not be assessed because there was no method of referring the map directly back to the originator. Despite this, the overall error introduced is considered low. For example, *Figure 4-7 Context Diagram Focusing on Concept No. 19 – Failure to Learn*, identifies some 34 links to the central concept, and even if a significant number of linked concepts were incorrectly attributed, a large number of links would remain. Concept No. 19 'failure to learn' is most important: this is intuitively obvious, ad the Coroner's meaning was clear in this regard. Further to the two-staged interview process described above, it will be discussed at Chapters 7, 8, 9, 10, that a slight methodological change was possible because the client group, the originators of the map, could be continuously engaged. In those cases, inter-coder reliability could be maximised by processes of validating maps directly with the originators, and using the schema described at *Table 7-1 Schema for Validating Causal Linkages.*

b. Identification of Important Nodes. Further to Annex A, and the methodology described at Chapters 3 and 4, methods for validating causal linkages and validating maps are explained at *7.1 Validation of Concept Maps*. Identifying important nodes involves more than identifying the number of connected nodes; an assessment of the strength of influence must be made at each stage of map development. A good test is to gauge the effect on the node under consideration that is produced by the trial removal of selected linked nodes. Where the effect is small, the connected node may be considered unimportant. Similarly, if removal of a specific node destroys the logic or minimises the influence, then that node is important. This also assists in determination of what to include within the map. This is demonstrated further in the tutorial at Chapter 7.

c. Where and Which Way to Draw Links. It is not uncommon for different individuals or groups to produce maps that vary, even when presented with the same information. This is because each of us has different ways of interpreting our world experiences. Kelly (1955) identified this in his original theory of personal constructs. What is important is that maps produced, either as individual (cognitive) maps or group (concept) maps do not contain ambiguities. Doubt about where and which way to draw links in a concept map, can be minimised by following the procedure described at *7.1 Validation of Concept*

Maps and using the schema described at *Table 7-1 Schema for Validating Causal Linkages*.

d. Objectiveness of Concept Maps. Application of the two-stage process described above at 4.14 a. is intended to ensure maps developed as a result of interviews faithfully reproduce the views of the interviewees. The processes described in the tutorial at Chapter 7 are designed with objectivity in mind. When developing concepts from documents, as was done here at Chapters 3 and 4, the same mechanisms, which would otherwise to minimise the introduction of biases, do not exist. Consequently, the maps produced are the sole interpretation of the person who develops the map and the interpretative skill of that individual.

4.15 Risks Associated With Amalgamation of Maps

Q. What are the difficulties associated with amalgamating cognitive maps from interviews with the various stakeholders?

A. Significant risk to the research method exists where maps are amalgamated, combined or summarised to higher levels of aggregation.

Consider the amalgamation of maps from two reports by different authors on the same subject, or produced from interviews with two separate interviewees on the same subject.

The researcher has to contend with:

a. potentially disparate perspectives;

b. idiosyncrasies in the use of language; and

c. individual use of fuzzy logic in the psychological constructs portrayed in the maps.

Considerable skill in interpretation is needed. So, interpretation should be done in consultation with the interviewees or authors. Working in a group setting places the interpretive task back on the originators, that is, the owners of the cognition. Eden and Ackermann argue:

> Cognition belongs to individuals, not to organisations; the attribution of cognition to an organisation is problematic and depends completely upon the legitimacy of

> reification. Even if reification can be justified on the practical grounds that doing so allows the research question to be addressed, the source data are dependent upon eliciting material from individuals or small groups, or from documents written by individuals or a team… what is written in documents is mediated by considerations of formality, audience and record keeping. The issue of reification is further exacerbated once the relationship between emotion and cognition is recognised; emotion can only belong to an individual (Eden and Ackermann, 1998b: 193).

Individuals working together can produce a joint, and agreed, map. But, working alone, the mapper produces an amalgamated, third perspective. That does not mean such a perspective is invalid. If there is high levels of agreement in the original maps, amalgamation is less difficult. Where significant differences exist in the original maps, considerable skill needed and objectivity could be threatened. It is more likely that findings will be inconclusive.

Where findings are inconclusive (indeed in all cases) the maps can be used to facilitate dialogue. Dialogue can result in creation of a new view. The most important aspect is that, correctly managed, dialogue can result in critical analysis of individually held, ingrained assumptions.

Kelly (1955) makes the point that our personal constructs are continually being reviewed and re-constructed. We continually evolve our personal constructs. Our views of the world today are not necessarily our views tomorrow… our personal constructs change continually, incrementally.

This does not mean radical change. The overall structure influenced by our systems of meaning may remain largely unaltered [unless deeply ingrained assumptions are challenged and as a result of critical review, reconstructed].

4.16 Projecting Lessons Learnt – Preparing for the Future

Q. What different approach do you take to prepare for the future?

A. From a partial map, based on what is reasonably known today, the likelihood associated with each link can be estimated. In this way we create a risk assessment for the most likely ways through the maze, from now to the future. In effect we create a set of Faustian Trees. Each causal link is treated as a one-way route. Each connotative link is treated as operating in either direction.

This is a form of futures analysis. Future scenarios would have to be built. How the Faustian Trees fit with the scenarios has to be treated on a case-by-case basis.

4.17 Summary – Chapter 4

In each of the case studies, a common thread was reliance on erroneous views of one or more critical stakeholders. In the Katie Bender case, we saw how there was an almost religious reliance on the expertise of the shot-firer. This expertise was flawed: the consequences were tragic. In the Black Hawk case, in Chapter 3, there was heavy reliance on the inexperienced Flight Lead pilot. This proved similarly tragic. Reliance on Defence's maintenance contractor led to short-cutting of Naval configuration management procedures, which led to the tragic fire aboard HMAS WESTRALIA.

At Esso Longford, after complaining to managers that there were safety problems – only to be reassured that a recent safety audit by the parent company Exxon found the No. 1 Gas Plant to be safe, workers repeatedly ignored alarms. They relied on management's assurances. These alarms warned that the gas production processes were running out of tolerance. This included heat exchanger GP905 which cooled dangerously below its normal operating temperature. Cold temperatures followed by the introduction of warm liquid ruptured this heat exchanger. In turn, this resulted in the release of a large volume of hydrocarbon vapour, which ignited giving rise to a series of explosions and fire.

The cases studied in this chapter contain a number of disturbing similarities to the Black Hawk helicopter crash studied in Chapter 3. The critical common thread is failure to appreciate, or understand, the inherent detail and dynamic complexity and underlying systemic structures. In turn, this became a major contributor to the failure to learn (from experience) and failure to manage the most influential risk factors, that is, those having the greatest consequence.

This raises an important challenge; to find effective ways to help stakeholders and decision-makers, alike, to become familiar with the cues associated with 'messy' or 'wicked' problems in order to catch them before they develop, or to minimise their consequences. This involves recognising their characteristic nature. Only then can effort be directed toward investigating underlying systemic structures and where effort might be directed to greatest effect.

In this chapter, the theme of failure to understand inherent complexity, failure to learn and, hence, failure to manage most important risks, is strengthened. Evidence presented here is that managers and decision-makers repeatedly failed to appreciate the significance of the complexity they faced. Further to Chapter 2, the suggestion is that they had unacceptably low rates of recognising or responding to highly relevant cues. This occurred despite recognition being a powerful human cognitive capacity. This suggests that the context did not enable recognition to occur, noting that recognition is highly context dependent. It is also obvious that other influences such as politics stifled or precluded the taking of necessary remedial action.

The deduction from the cases studied in Chapter 4, building on earlier chapters, is that problem conceptualisation efforts should be directed at creating the context within which recognition is enabled. It will be argued in subsequent chapters that how the context is created is not so important. The important issue is that the context is created. In subsequent chapters, how to create that context will be investigated, as will barriers to achieving it.

4.18 Significant Contributions Made in Chapter 4

From the empirical case studies, it is clear that managers and decision-makers can spend a good deal of their time being unaware of exactly what is developing around them. So, they become ineffective in meeting their responsibilities, or duties of care, to routinely rectify what, otherwise, might develop into insidious, systemic problems. This work suggests that the focus should remain directed at finding effective ways of enhancing situational awareness among managers and decision-makers. Situational awareness means more than developing ecological efficiency in use of heuristics, it means developing experience and understanding of behaviour of systems and systems-of-systems.

This chapter studied a number of cases from a systemic viewpoint, but studied one particular case in detail. It was found that underlying every systemic problem is a set of causal interrelationships, or ‘structures’, which create the environment for undesirable, or catastrophic, outcomes. These structures can exist and go uncorrected for periods of years. But a reasonable person, with reasonable situation awareness should be able to identify systemic problems. If that person is in a position of responsibility, it is reasonable to expect they would make corrections that should routinely obviate the opportunity for undesirable or catastrophic outcomes to develop. As obvious as it seems after-the-fact, this describes risk management. These cases have significant theoretical and practical implications for the development of risk management strategies. Findings from this and the preceding chapter will be incorporated in the principles of method described in Chapter 6.

CHAPTER 5: COMING TO GRIPS WITH 'WICKED' PROBLEMS

Synopsis

The preceding chapters established the need for this research effort by looking at a number of real-life case studies. At the root of each was a complex, dynamic and systemic web of interrelationships. It is this web of interrelationships and ever-changing influences, which creates many of the difficulties we experience in managing effectively. So, it becomes the primary subject of interest.

The nature of these 'wicked' problems is characterised with a view to providing insights into how we might develop methods for identifying, analysing and managing them. This chapter also reviews the literature with particular focus on what various researchers have observed about complexity and human ability to make decisions, develop strategy and policy in the types of environments typified by the case studies. It also considers related activities including problem conceptualisation, problem solving, understanding, learning, and communicating.

End products of this chapter are principles of a proffered methodology to address wicked problems. Unfortunately, it becomes readily apparent that to identify the principles then combine them as a coherent methodology, see Figure 5-1, is not a simple task. The task is clouded by arguments in the literature about the use of systems thinking and system dynamics techniques.

This chapter also introduces some of the factors that militate against our effectiveness in dealing with complexity in organisational contexts.

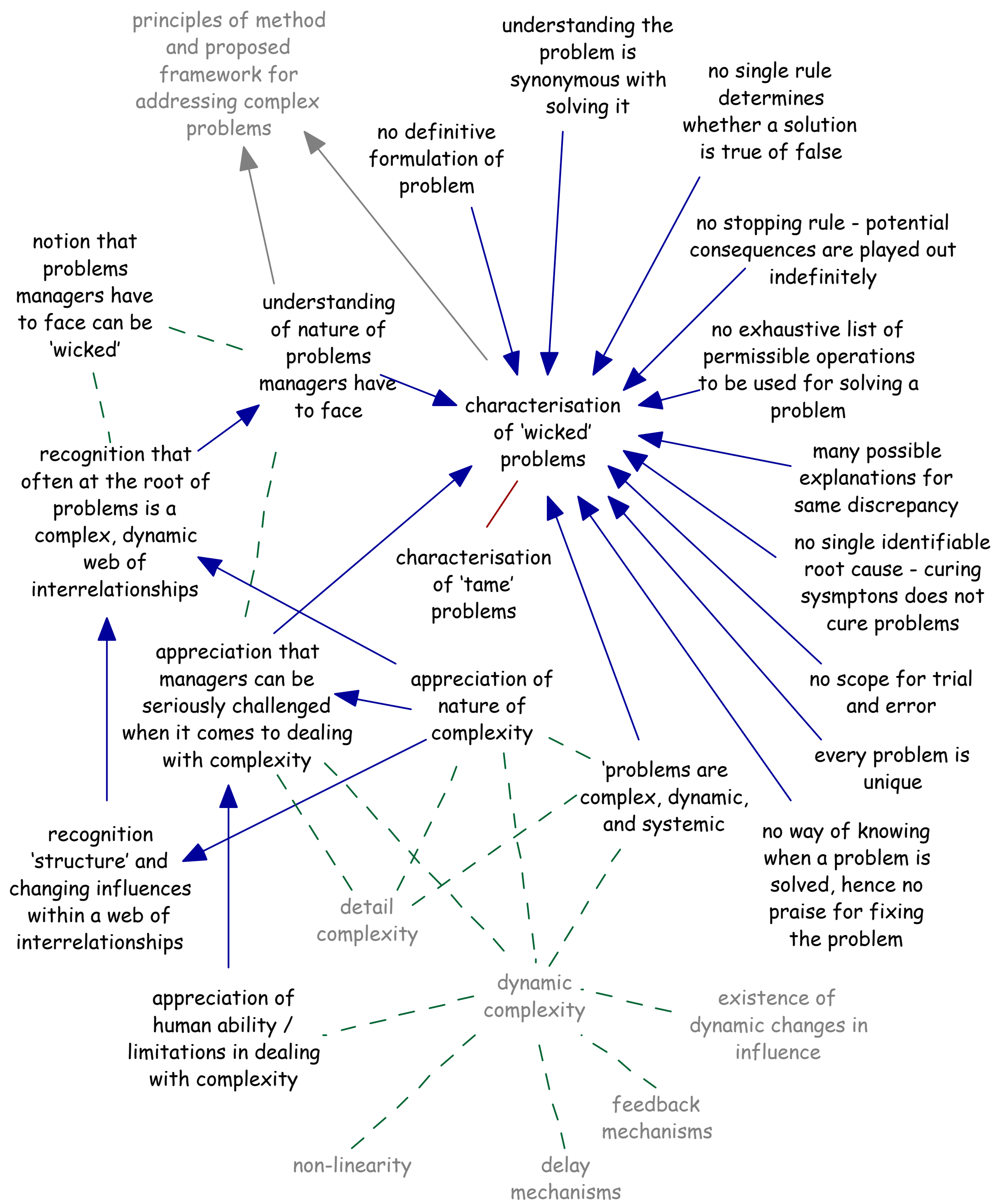


Figure 5-1. Concept Map - Chapter 5 Synopsis (1)

<u>Note:</u>

1. Concepts shown in black text are contained in this chapter.

When we try to manage problems, such as those in the cases studied, at Chapters 3 and 4, we often encounter recurring difficulties. These difficulties can be the delayed consequences of earlier corrective action. This stems, in large part, from both the nature of complexity and from finite limits to our capability and capacity to understand and learn in complex, ever-changing environments.

Those who understand the true nature of these environments use terms such as ‘messy’ or ‘wicked’ to describe them. To most of us, they are very familiar, even normal. We face them every day of our lives. We are part of them: that we are human is both a common and contributory element.

When faced with such problems, particularly in their juvenile forms, we simply see them as sources of frustration. We may even fail to recognise their existence: we may not consider them problems at all. At times we will deliberately choose to ignore them, re-directing our attention, instead, to more pressing issues. The challenge is to recognise them for what they are.

Traditional ways of thinking and traditional analytical methods have been shown to be largely ineffective in providing the understandings we need when faced with dynamic complexity, where delayed feedback occurs. There is a body of evidence suggesting human cognitive capability is not up to the task of dealing with the levels of complexity found to exist in the case studies. Further, the way we think about these complex, dynamic, systemic problems can be quite inappropriate.

Systems thinking and system dynamics can help our quest to understand better and to learn about complexity and complex, dynamic problems. The case studies and the literature search provide a number of leads toward what we might need to consider when designing a framework for addressing wicked problems.

5.1 Brief Reflection on the Black Hawk Helicopter Crash

If we had had the responsibility of commanding either of the Army units involved, designing and managing training overall of this Counter Terrorist (CT) / Special Recovery Operations (SRO) training activity, in particular, in the days, weeks, or months before 12 June 1996, what would we have done? Of course, we would have no knowledge of the catastrophic events that were about to unfold, but we would be faced with various warning signs and symptoms.

The management and decision-making tasks in our spotlight are complex. They are complex both in their detail and their dynamics. Despite commanders and staff officers being well trained, the problems they have to manage can elude their efforts and their considerable intellect. As workloads and stress increase, or dynamic feedback structures, inherent in the problems, begin to manifest themselves, decision-making and management become messy. Managers become less able to cope effectively. In turn, they place greater reliance on their individual and privately held knowledge, experience, judgement, and intuition. Often, as the accident case studies suggest, this may not be enough. Indeed, when it comes to dealing with dynamic complexity, it may be inappropriate.

As explained at 2.25 complexity is not the only issue here, there are many others including:

a. limited access to, or availability of, relevant information;

b. erroneously reported information;

c. information deliberately withheld, such as through fear, ignorance or uncertainty, or simply because its significance is not understood;

d. ambiguity;

e. conflict between stakeholders;

f. limited span of responsibility which precludes taking an ‘arms-length’, holistic view;

g. limited influence;

h. assumptions developed from prior experience that are not completely relevant, are incorrectly interpreted and applied, or may even be erroneous; and

i. thinking in terms of ‘gold nuggets’ that is, extant problems can be corrected if a single cause can be removed.

The list above has been developed primarily from observations made during case study research. At this point it is sufficient to recognise that these issues exist and that their importance should not be underestimated. Others such as Nutt (1989) have developed their own lists and proffer them as reasons for poor decision making or failures in organisational change interventions. They are omnipresent; it is only the extent of their impact which varies. They have a significant impact on the way we might set about designing strategic interventions or developing decision-support systems.

5.2 Why Complex Problems are Difficult to Manage

None of these wicked problems, described in Chapters 3 and 4, arose over a short period or without warning. In each, the crucial and highly influential ‘before’ period, during which systemic structures, the precursors to the ultimate tragic outcomes, were found to exist, were years long. Over these periods of years, warning signs appeared, but were ignored or were not acted upon in any meaningful way. Whatever was done was ineffective. This alone is problematic.

We could well ask why warning signs were ignored or did not ring alarm bells among managers involved, participants or casual observers. Part of the answer lies in the failure to recognise the warning signs for what they were. Because the warning signs were not seen in the context of the whole problem, they were taken as normal, albeit untidy or undesirable. They were seen as isolated or, at best, loosely linked events. Whilst some concern was expressed about them, little follow-up action was taken.

Sterman (2000) observes that many such problems arise as the unanticipated side-effects of our own past actions. Often these side effects are not recognised as being linked to what has gone before, including our past actions, because of delays in system response. Delays may vary from days to years. When the underlying systemic structures manifest themselves as feedback and delay, or changing feedback loop dominance, problems behave in counter-intuitive ways (Forrester, 1961).

In each of the cases studied, symptoms that suggest something insidious was developing existed in varied forms, although there were many common ones. In the Black Hawk case, morale among pilots had been a long-standing problem. Closer to the crash there was frustration, tension and uncertainty among pilots, and between pilots and their Officer Commanding (OC). Despite apparent confusion about the mission to be flown that fateful evening, and concerns about safety, the OC insisted the exercise would proceed.

5.3 Characteristics of Wicked Problems and Strategies for Addressing Them

The nature of wicked problems has been introduced. However, before determining how we might recognise triggers, symptoms, warning signs, root causes, and underlying systemic structures, which produce dynamic behaviour, it is both valuable and important to reflect further upon the nature of wicked problems:

> Wicked problems are not necessarily wicked in the perverse sense of being evil. Rather, they are wicked like the head of a hydra. They are and ensnarled web of tentacles. The more you attempt to tame them, the more complicated they become (Mason and Mitroff, 1981: 10).

The review contained in this chapter is intended to provide insights into addressing such problems. Wicked problems are complex and systemic. They can be insidious, growing like a cancer. When we become aware of them, we may find they are difficult to resolve. We might make what we believe to be a valid change, implement what appears to be rational and logical policy or strategy, only to find we still have problems. They change form, adapt, reorganise, and reappear as a mutation. Thus ‘wicked’ is an apt description.

Wicked problems are ubiquitous and inescapable. We live very closely with them in our daily lives. We are often an integral part. Unlike physical problems where laws, such as Newton’s Laws of Motion govern behaviour over time and ensure both predictability and repeatability, when people are involved there can be many surprises. With these ‘human systems’ it can be exceedingly difficult to predict behaviour.

The concept of wicked problems is not new. Rittel (1972) defined a set of properties distinguishing wicked problems from others he describes as ‘tame’. Mason and Mitroff, (1981) use Rittel’s definitions. They will suffice as a starting set.

The following list is based around Rittel’s criteria for discriminating between tame and wicked problems. Rittel’s criteria and descriptions are shown in italics. Comments in plain text are those of the author of this dissertation.

5.4 Tame *vs* Wicked Problems - *Ability to formulate the problem*

Hypothesis: Tame problems can be exhaustively formulated and written down on a piece of paper.

Wicked problems have no definitive formulation.

Comments: Before we might understand extant problems, and what the future might hold, we are challenged to deal simultaneously with detail and dynamic aspects of complexity. These are inextricably linked to the underlying systemic structures.

Detail complexity describes myriad, interrelated factors or forces, just too many to be considered at any one time. Dynamic complexity describes something insidious and self-organising.

Many wicked problems are exceedingly complex. Problems we often face within socio-technical organisations are characterised by $C = 10^n$, where n is within the range 6 to 13 (Kline, 1995: 49-68). Clearly, such problems cannot, in any practical sense, be exhaustively formulated. Those problems that can be exhaustively formulated and reliably solved are characterised by $C < 5$ See 1.1. The complexity of wicked problems can be many orders of magnitude greater than tame problems.

Vennix (1996) notes the one of the most pervasive characteristics of the existence of wicked problems is that people hold entirely different views on whether there is a problem, and if they agree there is, what the problem is. He also suggests that wicked problems can be quite intangible. Various authors, including Ackoff (1981), Checkland (1981), and Checkland and Scholes (1999) have also suggested that in these circumstances there are no 'objective' problems. Vennix (1996: 13) suggests there are only situations defined as problems, by people closely involved.

Difficulty in formulating wicked problems comes from inherent dynamic complexity. Dynamic complexity is typified by being; dynamic, tightly-coupled, governed by feedback, non-linear, history dependent, self-organising, adaptive, counter-intuitive, policy resistant, and characterised by trade-offs (Sterman, 2000: 21-22).

Before we can solve wicked problems, we need to identify and understand what underlies and produces spontaneous self-organisation: we need to understand the relationship between systemic structure and dynamic behaviour.

Problem formulation may be fostered by use of various intellectual devices, which accommodate the imprecise or incomplete understanding of the problem as it is first encountered. These devices variously incorporate language, icons and symbols to record ideas, help document and surface assumptions, and to aid communication.

These are useful because of their richness and their ability to facilitate the elicitation of ideas, triggering of new ones, and revealing gaps in the association of ideas (Hodgson, 1992). Tools that might be used to achieve this are:

- Cognitive (or concept) mapping (Eden, 1988).

- Rich pictures, as part of the Soft Systems Methodology (Checkland, 1981).
- Influence diagrams (Coyle, 1977; 1996).
- Causal-loop diagrams (Richardson and Pugh, 1981; Senge, 1981; Sterman, 2000).
- Hexagons (Hodgson, 1992).

Language and communication lie at the heart of expressing ideas about problems. Without effective communications dialogue will fail, assumptions will remain hidden and problem formulation efforts will be stifled. Symbols and icons are valuable aids to communication. They are rich in meaning the expression of which is vital to problem conceptualisation.

Particularly in a group problem-solving setting, use of these devices may encourage alternate perspectives to be brought into the dialogue. However, when it comes to use of symbols and icons, it must be noted that each of us may attach different meaning to them and have different feelings about them.

Arguably, only music and mathematics are universal symbolic languages: there is a minimum of scope for interpretation of what is written. But, in discussing the nature of problems and writing down their formulation there are many language, communication, emotional, perceptual and cultural considerations.

Some of these can be alleviated by use of devices listed above. Unfortunately, the devices listed are not universally applicable and use requires significant skill. We need to recognise that in the design of strategy development interventions. One way to accommodate this is to have a range of tools, techniques and devices in our toolbox.

5.5 Tame *vs* Wicked Problems - *Relationship between problem and solution*

Hypothesis: Tame problems can be formulated separately from any notion of what their solution might be.

Every formulation of a wicked problem corresponds to a statement of solution, and vice versa. Understanding the problem is synonymous with solving it.

Comments: Developing a detailed understanding of the nature of the problem, its structure and dynamic behaviour is an essential precursor to taking effective steps to finding a solution. This was demonstrated by the Black Hawk helicopter crash case study. That is just one specific example of a wicked problem. In Chapters 3 and 4, it was argued that there was no single direct course of action that would lead to a solution. If a solution had been effectively implemented, it may have averted the final tragic outcome, but there is no absolute guarantee here.

Further, there is a paradox: had real understanding of the problem existed, and effective corrective action been routinely applied, there is no way that it could be known that tragedy had been averted.

The importance of producing understanding and learning as pre-conditions to developing an effective solution is now widely accepted (Coyle, 1996; Eden and Ackermann, 1998; McLucas 1998: 1999: 2000; Morecroft and Sterman, 1994; Roberts, Andersen, Deal, Garet and Shaffer, 1983; Sterman, 2000; Vennix, 1996).

Described below (with minor variations) is the system dynamics modelling approach to addressing wicked problems, developed from the seminal work of Richardson and Pugh (1981). This approach is applied very widely in contemporary system dynamics practice by leading researchers and practitioners Coyle, Homer, Sterman, Vennix and many others:

> There are roughly seven stages in approaching a problem from the system dynamics perspective:
>
> - problem identification and definition,
> - system conceptualisation,
> - model formulation,
> - analysis of model behaviour,
> - model evaluation,
> - policy analysis, and
> - model use or implementation.
>
> The process begins and ends with understandings of a system and its problems, so it forms a loop, not a linear progression (Richardson and Pugh, 1981: 17).

Sterman (2000) stresses the iterative nature of learning and problem solving using system dynamics:

> … it is important to place the modelling process in context with the ongoing activities of the people in the system. Modelling is a feedback process, not a linear sequence of steps … one will iterate through these steps many times (Homer, 1996). Most importantly, modelling is embedded in the larger cycle of learning and action taking place … (Sterman, 2000: 87-88).

5.6 Tame *vs* Wicked Problems - *Testability*

Hypothesis: Solution of a tame problem can be tested. Mistakes and errors can be pinpointed.

There is no single criteria system or rule that determines whether the solution to a wicked problem is correct or false. Solutions can only be good or bad relative to one another.

Comments: In an attempt to determine whether a solution is correct or false, we iterate (Homer, 1996). 'Reference modes of behavior' (Richardson and Pugh, 1981) are identified then replicated by modelling. Simulations are repeatedly run with aims of validating against the reference modes of behaviour and to build confidence that the models replicate reference modes.

This is a trial and error process. So, there can be no definitive testing of multi-dimensional system dynamics models by re-inserting the solutions back into the whole set of equations contained in the model(s), and under all possible conditions, and for the whole parameter space.

This is exacerbated by the fact that system dynamics models contain difference equation approximations of differential equations. Consequently, the 'correctness' of such models cannot be gauged in absolute terms. Models can only be assessed in terms of their ability to replicate the observed behaviour. In practice, it becomes even more difficult. We may be constrained, by our data collection methods or our perspective of the problem, to observing only some of the complete set of reference modes.

We cannot be certain that when modelling what we believe to be complex, we are facing behaviour that may become chaotic at least some of the time. It can be extremely difficult to determine that the problem at hand is complex and does not have a chaotic mode. Andersen (1988) explains that whilst one justification for quantitative modelling is to detect chaotic behaviour, unless researchers are trained to look for the precursors to chaotic dynamics ….

> … even in those systems that do contain chaotic modes, the chaotic mode appears only elusively. That is, a chaotic mode will only exist for some specifically defined area or volume within parameter space. Since for most models this parameter space is many-dimensioned, and since all chaotic models are nonlinear, moving in a straight line or along a plane through parameter space may take the analyst in and out of the chaotic region in a seemingly unpatterned way. Thus, even when one is operating in the vicinity of a chaotic mode in a parameter space, the chaotic mode can apparently vanish, given a seemingly small change in one of the model's parameters (Andersen, 1988: 7).

The following is particularly problematic for us when we set out to investigate dynamic behaviour of something which, on the surface, appears to be moderately complex: the model may become chaotic unexpectedly.

> … Mosekilde and Larsen (1988) demonstrated that a simple model of a multichain distribution process exhibited very complicated dynamics, including a chaotic mode for selected parameter values. This example was particularly interesting because the same model [the 'Beer Game'] had been used for many years as a teaching example in many introductory classes in system dynamics … diagnosing chaos as well as the full range of dynamics in the model would have required running the model for a much longer time and then paying attention to the steady-state dynamics of the system after initial (but relatively long) transient effects had died out (Andersen, 1988: 5).

5.7 Tame *vs* Wicked Problems - *Finality*

Hypothesis: Tame problems have closure - a clear solution and ending point. The end can be determined by means of a test.

There is no stopping rule for wicked problems. Like a Faustian bargain, they require eternal vigilance. There is always room for improvement. Moreover, since there is neither an immediate or ultimate test for the solution to the problem, one never knows when one's work is done. As a result, the potential consequences of the problem are played out indefinitely.

Comments: Chapter Three demonstrated that preconditions for the Black Hawk crash developed in the early 1990s. Parliament was sufficiently concerned about serviceability of aircraft that the Chief of the Defence Force (CDF) was asked what he was doing about it. The CDF's corrective action was largely ineffective because of varying long lead-times for acquisition of critical spares from the United States. Aircraft availability remained unacceptably low.

Systemic delays, of variable and often unknown duration, can make the creation of effective strategies difficult, particularly when there are consequential 'knock-on' effects. The morale of pilots declined when training was affected by lack of serviceable aircraft. Strategies, including payment of flying bonuses did little to ensure retention of pilots.

The iterative approach to strategy development using modelling and simulation, is aimed at incremental improvement of potential strategies and demonstration of their adequacy. But, there is no clearly defined end point when seeking a solution to a problem:

> … it is natural that a … model should go through multiple rounds of revision and evaluation … the iterative process may, in theory, continue as long as the model fails to satisfy some evaluative criterion (Randers, 1980). However, there is always some further refinement that may be made … opportunities for model improvement are not always apparent or obvious and … scientific modeling is not about minimizing the need for model revision … but rather about recognizing model shortcomings and following through with solid improvements (Homer, 1996: 3).

Modelling is important in building understanding and learning about what causes the behaviour of complex, systemic problems. Understanding is an essential precursor to strategy development and the process of seeking a solution can involve repeated evaluation of models against observed behaviour, review of strategies, and adjustment (Coyle, 1977; Eden and Ackerman, 1998; Morecroft and Sterman, 1994; Richardson and Pugh, 1981; Sterman, 2000, and Vennix, 1996).

> … models are always in a continuous state of evolution … we should stress the process of modeling as a companion to, and tool for, the improvement of judgement and human decision making (Forrester, 1985: 134.)

Understanding and learning through modelling should enable development of effective strategies for addressing wicked problems. This should limit potential consequences of the problem that might otherwise be played out indefinitely.

5.8 Tame *vs* Wicked Problems - *Traceability*

Hypothesis: There is an exhaustive list of permissible operations that can be used to solve a tame problem.

There is no exhaustive, enumerable list of permissible operations to be used for solving a wicked problem.

Comments: Complex, dynamic problems cannot be encapsulated in what Kline (1995) describes as a *complete invariant paradigm*. More importantly, the notion of a complete invariant paradigm is an impediment to our thinking. It provides a ‘comfort zone’ where fundamental assumptions are most unlikely to be challenged. Whilst we remain unchallenged, we remain comfortable with no desire to change, thereby holding onto deeply ingrained assumptions and ways of thinking.

A complete invariant paradigm exists when there is a set of laws proven sufficient to faithfully, and completely, describe observed behaviour, and exceptions to these laws have not been found.

Newtons Laws, the physical laws describing motion are an example. Whilst it is acknowledged that Einstein’s Theory of Relativity challenges Newtons Laws under certain conditions, for physical problems at the macro-level Newton’s Laws form a complete invariant paradigm. Problems which fit within a complete invariant paradigm can be solved by an exhaustive list of permissible operations: they are tame.

There are no equivalents to Newtons Laws, no complete invariant paradigm, when it comes to describing, the behaviour of socio-technical organisations. Further, our organisations may have incredible detail complexity.

Another consequence of the concept of the complete invariant paradigm is that throughout our formal education we are taught to think in the context of closed systems and taking a reductionist approach to problem solving. This involves reducing to component parts, analysing the parts then reconstructing.

Caution is needed here because not all problems are amenable to a reductionist problem-solving approach. Some are not readily reduced to component parts. Even when they can be so reduced, the component parts do not make sense individually. They only make complete sense in the context of the whole. So, frequently it does not make sense to attempt to trace the contribution of each component to total system functionality. This is best demonstrated by an example.

> A bicycle is made up of a frame, two wheels, pedals, a drive chain, saddle, handlebars, and etc. Even when assembled we only have a machine. When we combine the bicycle and rider we also have control and motive power. The resultant combination is a highly efficient form of personal transportation. The bicycle and rider combine to form a system with 'emergent properties'. In this instance, it does not make sense to break down and prescribe a complete functional test for each component of the system. Remove any critical component and the system falls apart (Stevens, Brook, Jackson and Arnold, 1998: 94).

It does not make sense to prescribe a complete functional test for the brain of the rider. But the rider's brain processes eyesight, balance, and muscle coordination. This involves complex kinestatic feedback mechanisms. So the rider's brain only makes sense in the context of the rider/bicycle transportation system. Similarly, systemic 'wicked' problems cannot be broken down and solved by application of exhaustive sets of permissible operations.

Complex, dynamic problems are characterised by interacting feedback loops. In some systems these can be very large in number. For example, the human body contains over a thousand chemical feedback loops (Kline, 1995).

In general, feedback loops may be positive (reinforcing), or negative (balancing) in nature, made up of series of positive or negative links:

> a *positive* link means that if the cause increases, the effect increases above what it would otherwise have been, and if the cause decreases, the effect decreases below what it would otherwise have been … a *negative* link means that if the cause increases, the effect increases below what it would otherwise have been, and if the cause decreases, the effect increases above what it would otherwise have been (Sterman, 2000: 139).

Interacting feedback loops, with or without embedded delay mechanisms, form the structures that produce complex, dynamic patterns of behaviour. The dominance of one loop may give way to that of another, positive feedback may give way to negative feedback, and *vice versa*. Chaotic modes of behaviour may also result, these being produced by other mechanisms. Chaotic modes were discussed above under the heading of *Testability*, and are equally problematic here.

Under conditions of changing feedback loop dominance and stochastic delay, the behaviour of a wicked problem may become exceedingly complex. Wicked problems have been described as non-linear, tightly-coupled, self-organising, adaptive and policy-resistant (Sterman, 2000: 22). Forrester (1971) first described the counter-intuitive response of wicked problems to corrective action: policies or strategies intended to correct a problem result in counter-intuitive response.

The structure and behaviour of wicked problems cannot be described in conventional ways. Similarly, wicked problems are not amenable to conventional problem-solving methods such as linear algebra where there are a limited number of clearly enumerated operations, which might be performed in the process of finding a solution.

In contrast, strategies for correcting wicked problems are developed through:

- activities which result in mapping the structure of the problem;
- identifying influential mechanisms within the problem space; and
- identifying ‘pressure points’ (Coyle, 1996: 222) or ‘leverage points’ (Senge, 1990: 64; Klein, 1998: 111-119) to which intensive management effort might be applied.

Convention would suggest we identify all paths through the problem space. Even though the structure of the problem may be described, changing dominance produces time-dependent responses which are more likely to be stochastic than deterministic: traceability becomes somewhat problematic. Tests for each possible effect would require tracing through each possible path and doing so for the full range of parametric values likely to be encountered. So, there is no exhaustive, enumerable list of permissible operations to be used for solving a wicked problem.

5.9 Tame *vs* Wicked Problems – *Explanatory Characteristics*

Hypothesis: A tame problem may be stated as a ‘gap’ between what ‘is’ and what ‘ought’ to be and there is a clear explanation for every gap.

Wicked problems have many possible explanations for the same

> *discrepancy. Depending on which explanation one chooses, the solution takes a different form.*

Comments: As explained above, conventional problem solving methods are inappropriate for addressing wicked problems. Modelling and simulation are powerful tools aiding our quest to address such problems. However, caution is needed.

In the process of simulating wicked problems, it is possible that different analysts will build quite different models. Each model may produce the same, or very similar, patterns of dynamic behaviour. Unless these different models are comprehensively evaluated, it is quite possible they will be accepted as perfectly reasonable depictions of the problem space and used for strategy or policy development, with potential to produce quite different results.

In relation to the scientific rigour required in model development, Homer (1996) makes the following observation:

> … adherence to the scientific method is essential for developing models that will stand the test of time. Both client and modeler may be tempted at times to abandon the process, especially when the needed evidence [for comprehensive evaluation] is not readily available… the modeler must… not be satisfied with surface appearances… deep evaluation is… the modeler's responsibility… evaluation-based insights often help resolve controversies about what is really important in a system and what is not (Homer, 1996: 16-17).

Identification of what is really important, or highly influential, in a system will drive selection of pressure points or leverage points to which we might apply resources and management effort. If this process is flawed, strategies and policies we might derive from the models are also likely to be flawed.

Because wicked problems have many possible explanations for the same discrepancy, we need to be careful in:

- model building,
- testing, and
- deciding on which explanations regarding:

- system influence, and
- model behaviour we choose.

These risks may be minimised by the rigorous application of the scientific method:

[Real] science is, quite simply, the scientific method, the relentless iteration of induction and deduction, of precise hypothesis formulation and careful experimentation (Meadows and Robinson, 1985: 419).

5.10 Tame *vs* Wicked Problems – *Level of Analysis*

Hypothesis: Every tame problem has an identifiable, certain natural form; there is no need to argue about the level of the problem. The proper level of generality can be found for bounding the problem and identifying its root cause.

Every wicked problem can be considered as a symptom of another problem. It has no [single] identifiable root cause; since curing symptoms does not cure problems, one is never sure the problem is being attacked at the proper level.

Comments: In each of the accident cases studied, relevant concepts were found to be strongly-coupled. That is, there were many instances of one problem being a symptom of another. Concept mapping was used to reveal the true nature of causality. For example, Coroner Madden's 657-page report on the death of Katie Bender was dissected. A series of complex maps were built. Some contained over 300 concepts linked in highly interrelated ways. The structure of the problems mapped suggest that there were many issues to be addressed through multi-pronged strategies.

In his summation regarding one aspect of 'systemic failure in the project', for example, Coroner Madden focused on nine contributory factors. Seven (± 2) key concepts (or factors) were found in many such summaries. This accords with the 'magic number' identified by Miller (1956). However, the act of reducing the detail in a document to a level expected by readers can be problematic. In this case Coroner Madden carefully considered many tightly-coupled factors to produce his summary list. Not all analysts have the skills needed to produce such incisive summaries.

As aids to selecting the correct level of aggregation for problem consideration, that is the level of analysis:

- Coyle (1996) offers a 'cone of influence diagrams' as a conceptualisation tool, encouraging us to view and analyse problems at various levels, moving between those levels as needed to enhance understanding and analysis.
- Eden and Ackermann (1998) suggest we might consider a hierarchy of 'tear drops' within which goals, aspirations, and strategies are contemplated. They also suggest, at times, we take a 'helicopter view' of problems to enable thinking at various levels of aggregation.
- Checkland (1981) suggests we take a world-view, *weltanschauung*, made up of many different perspectives.
- Checkland also suggests we look for *systemicity* (Checkland, 1999), which is the systemic behaviour (produced by multiple feedbacks and delays) exhibited by systems or systems-of-systems. He and Flood (1999) caution against attempting to model complete systems or systems-of-systems. Rather they suggest we seek to understand the causes of systemic behaviour and learn to manage within the complexity.

5.11 Tame *vs* Wicked Problems – *Reproduceability*

Hypothesis: A tame problem can be abstracted from the real world, and attempts can be made to solve it over and over again until the correct solution is found.

Each wicked problem is [unique, and solving it can be] a one-shot operation. Once a solution is attempted, you can never undo what you have already done. There is no trial and error.

Comments: Trial and error development of strategy can be highly impractical in the real world. This lack of opportunities to develop and test our personal constructs (Kelly, 1956), or mental models (Senge, 1990) inhibits double-loop learning (Morecroft and Sterman, 1994). However we can develop and test strategies in virtual worlds without creating collateral damage.

Computing and modelling technology are fast becoming accessible to virtually everyone, meaning powerful analytical tools are now on the desktop. Previously they were accessible only to a select few.

With the availability of these new and powerful tools, our efforts can be redirected to using our intellect to recognise and analyse patterns of dynamic behaviour. In turn, this offers new opportunities to understand and learn. From the point of view of this research, this also offers unprecedented opportunities for involving those closest to, and affected most by, complex problems. Moreover, it offers a chance to change the way we go about addressing complex systemic issues:

> … as computing proliferates, it becomes more important to recognise that computer tools are but a means to a promising end - insight into the behaviour of complex systems. The often puzzling behaviour of complex social systems, we postulate, can be usefully analysed and influenced by understanding the internal structure of the system. That internal structure is characterised by networks of conserved stocks and flows, loops of information feedback and circular causality and shifting patterns of loop dominance. Understanding the processes that endogenously produce the dynamics of real systems is often the purpose of a system dynamics study (Richardson, 1985: 1-2).

Morecroft and Sterman (1994) highlight the advantages of virtual world modelling. Virtual world modelling provides opportunities to repeatedly test a policy or strategy in a benign environment prior to foisting it onto the real world with attendant risks. Virtual world modelling also provides vitally important opportunities for learning about dynamic behaviour and what generates that behaviour.

5.12 Tame *vs* Wicked Problems – *Replicability*

<u>Hypothesis:</u> The same tame problem may repeat itself many times.

Every wicked problem is essentially unique.

<u>Comments</u>: Because each wicked problem is likely to be different to anything we have met before, we have to be careful about making assumptions, applying those assumptions to the problem situation, and relying on them during strategy formulation. To be safe, we should expect every new problem we confront is wicked until we can conclude otherwise.

Meadows (1989) identifies some 17 common assumptions that are problematic in what she calls the ‘current industrial paradigm’. She says these are:

> … partly or wholly false, that they are implicit or explicit in virtually all public discourse, that they give rise to much of the persistent counterproductive behaviour of individuals and institutions, and that the harm done by them is incalculable.

Erroneous or ill-founded assumptions that reduce our opportunities for effectively addressing wicked problems include:

- One cause produces one effect.
- A problem does not exist nor is it serious until it can be measured.
- Relationships are linear, non-delayed, and continuous; there are no critical thresholds, feedback is accurate and timely; systems are manageable through first-order negative-feedback-loop thinking.

Forrester (1985), Lane (1993b.), Morecroft and Sterman (1994), Richardson and Pugh (1981), Sterman (2000), Vennix (1996), and Wolstenholme (1990), are strong advocates of modelling as an important enabler to understanding and learning. They put forward compelling arguments to support the hypothesis that a highly effective way of improving our understanding of [unique, wicked] complex, dynamic problems and to promote learning is to model them. In modelling as learning (Lane, 1993b.; Morecroft and Sterman, 1994), cycles of virtual world modelling and simulation are used to test assumptions and build understanding of complex, dynamic problems through double-loop learning (Argyris, 1985).

Modelling and simulation need to be done with care and scientific rigour (Homer, 1996) for learning to occur without error. Modelling and simulation for purely exploratory purposes without scientific rigour can be misleading. Comprehensive verification and validation are also required. Practical difficulties of validating and evaluating models mean there is always room for improvement:

> … some important data will be in error, irrelevant, missing, or slow to emerge. Such data problems can slow things down and may require a change in tactics. One may need to look to other sources for data, or consider using different variables or levels of aggregation to capture the same phenomena. Or, one may simply move forward with the existing model and data and accept a lower level of confidence until such time as

better data become available (Homer 1996: 17).

The need for caution comes from a variety of sources. Wicked problems are dynamically complex and may have chaotic modes. This is not readily ascertainable, nor is it always clear that models are behaving the way they are because the models are correct or because they are incorrect. They may even be based on incorrect data. However, these difficulties can be overcome through the application of scientific methods, building quality ‘fit for purpose’ models and continual validation.

5.13 Tame *vs* Wicked Problems – *Responsibility*

Hypothesis: No one can be blamed for failing to solve a tame problem, although solving a tame problem may bring some acclaim.

The wicked problem solver has ‘no right to be wrong’. He is morally responsible for what he is doing and must share the blame when things go wrong. However, since there is no way of knowing when a wicked problem is solved, very few people are praised for grappling with them.

Comments: As suggested above in relation to the Black Hawk helicopter crash, seeking, after the event, to find those responsible threatens learning opportunities. If learning was more effective, risk management would be similarly more effective. Problems would be routinely corrected and disasters averted.

The public demands wicked problems be managed and, hence, politicians are bound to act. Similarly, shareholders rely on company directors and executives to avoid litigation that might follow an accident or environmental disaster.

Anybody in authority who designs policy, develops plans and strategies, or makes decisions has a duty of care to those who might be affected by policies, strategies or decisions they create. Regardless of any legally defined duty of care, there are ethical duty of care considerations here. Churchman (1961; 1971) argues strongly that ethics are an integral part of decision-making. Flood (1999) explains that Churchman spent his life dedicated to humanity. His commitment begins and ends with humanity in scientific research. Churchman insists that scientists [policy designers, strategy developers and decision-makers, and the like] must take responsibility for the social consequences of their work. Legal or ethical duty of care is owed to all stakeholders who, knowingly or unwittingly, are affected.

Stakeholders include employees, shareholders, and the public. Duty of care can only be exercised with full ethical responsibility when policy designers, strategy developers, and decision-makers understand risks associated with their policies, strategies and decisions. If risks are ignored or are seriously misunderstood, by those who have a duty of care, they may well be abrogating their responsibilities to those that might be affected.

The nature of wicked problems mean we are unable to, or may be restricted in our ability to:

- definitively test that solutions or strategies we develop are sufficient;
- determine, in many cases, that the problem or the model of that problem does not contain a chaotic mode;
- find a ‘final’ version of the model that gives us confidence that we can investigate all possible modes of behaviour across parameter space; or
- faithfully replicate the problem to an extent that we have a very high degree of confidence in the model of the problem and strategies we might derive from modelling and simulation.

Each of these impact on our ability to fulfil the duty of care responsibilities to the extent advocated by Churchman. The practical consequence is that strategies derived from modelling and simulation will be delivered with disclaimers about the extent to which strategies can be developed from such models. However, this may not be acceptable to stakeholders who see we problem solvers as ‘having no right to be wrong’.

5.14 Other Characteristics of ‘Wicked’ Problems

Mason and Mitroff (1981) explain that most policy planning and strategy problems are wicked problems of organised complexity. Further to the characteristics listed above, complex wicked problems also exhibit the following characteristics, based on an original list prepared by Professor James Jackson at UCLA Graduate School of Management (Mason and Mitroff 1981: 10-13):

a. *Interconnectedness. Strong connections link each problem to other* *problems. As a result these connections sometimes circle back to form feedback loops. 'Solutions' aimed at the problem seem inevitably to have important opportunity costs and side effects. How they work out depends on events beyond the scope of any one problem.*

Also see Tame *vs* Wicked Problems - *Level of Analysis*, at 5.10, above.

Similar observations are made by Forrester (1961), Kline (1995), Richardson (1991), Senge (1990), and Sterman (1994). Both Beer (1966) and Flood (1999) observe that the boundaries we draw around the problem impact upon inclusion or exclusion of parts of interrelated problems. How we draw boundaries also has a significant effect on who we include or exclude as stakeholders in both the problem and solution spaces.

b. Complicatedness. *Wicked problems have numerous important elements with relationships among them including important 'feedback loops' through which a change tends to multiply itself or perhaps even cancel itself out. Generally, there are various leverage points where analysis and ideas for intervention might focus, as well as many possible approaches and plausible programs of action. There is also a likelihood that different programs should be combined to deal with a given problem.*

Complicatedness is a synonym for complexity. A key to understanding complexity comes from reflecting upon what Coyle (1996) and Richardson and Pugh (1981) call the 'reference modes behaviour'. These reference modes aid in characterising the underlying dynamics and form the baseline for detailed analysis. They help us identify triggers and root causes of problems and help put various symptoms in context.

Senge (1990) reminds us that there are two forms of complexity; detail and dynamic. Detail complexity means there is extensive interrelatedness among myriad underlying factors. Detail complexity arises where there are many variables, which are difficult, if not impossible, to hold in the mind at once and appreciate as a whole.

Dynamic complexity means the magnitude, and influence of forces acting at any point in time, varies. Senge explains that dynamic complexity arises where effects over time of interrelatedness are subtle and the results of actions are not obvious; or where short term and long term effects are significantly different; or where effects locally are different from effects on a wider scale.

A model of detailed complexity can be likened to a snapshot photograph that allows detail to be studied in a freeze frame. A model of dynamic complexity can be likened to an animation that allows patterns of behaviour to be studied over time (Flood, 1999: 1-2).

Flood suggests that we have to accept the impracticality of trying to solve completely those massively complex problems where dynamic complexity prevails.

We become overwhelmed by ‘the induction problem’, that is, our inability to observe a series of events and induce rules and relationships. We often lack the ability to see a clear link between cause and effect. Too many variables intervene, time delays [and feedback mechanisms] create their own complications (Klein, 1998: 280).

Forrester (1961) makes the important observation that it is feedback and delay structures that determine dynamic behaviour. Forrester (1961), Coyle (1996), Richardson (1991), Senge (1990), and Sterman (1994) reinforce this observation. The critical issue here is to be able to identify the leverage points. If we don’t uncover the existence of feedback and delay structures and the influence they have, we are challenged to identify and exploit these points to best advantage.

c. <u>Uncertainty</u>. *Wicked problems exist in a dynamic and largely uncertain environment, which creates a need to accept risk, perhaps incalculable risk. Contingency planning and also the flexibility to respond to unimagined and perhaps unimaginable contingencies are both necessary.*

Nutt (1989) identifies uncertainty, ambiguity and conflict as symptomatic of situations where tough decisions have to be made. See sub-paragraphs d. and e. below. Risk management thinking and practice help us to identify risk (uncertainty), place it in context and manage it, thereby reducing ambiguity and potential for conflict. Klein (1998) and Lipshitz and Shaul (1997) describe uncertainty as doubt that threatens to block action. Key pieces of information are missing, unreliable, ambiguous, inconsistent, or too complex to interpret, and as a result a decision-maker will be reluctant to act (Klein, 1998: 267). Klein observes that effective decision-makers accept the inevitability of uncertainty:

> Because uncertainty is inevitable, decisions can never be perfect. Often we believe that we can improve the decision by collecting more information, but in the process we lose opportunities. Skilled decision makers appear to know when to wait and when to act. Most important, they accept the need to act despite uncertainty (Kline, 1998: 279-280).

This creates critical demands on those who build decision-support systems. Decision-support must be timely and fit within the decision-maker's decision-cycle. See 2.20.

d. *Ambiguity*. Ambiguity arises when key elements in a decision cannot be characterised (Nutt, 1986: 6) or are not typical (Klein, 1998: 32-33). See 2.19. Ambiguity is created when patterns of events do not fit right, when decision-maker's expectations are violated so it becomes unclear as to what is going on. When decisions seem too complex to sort out, decision-makers may 'muddle through', do what others are doing, or ignore the decision by treating it as unimportant. Ambiguity can be repressed, or avoided, but by doing so often creates anxiety and may lead to recasting the problem in ways that ignore core issues, or which leads to superficial treatment.

e. *Conflict. The problem can be seen in quite different ways, depending on the viewer's personal characteristics, loyalties, past experiences, and even on accidental circumstances of involvement. There is no single 'correct view' of the problem.*

Tools and techniques that might be used to help overcome ambiguity need to:

- provide insights into multi-factorial causality.
- enhance appreciation of dynamic complexity, and

- accommodate a variety of potentially disparate or conflicting views.

Similar observations are made by Nutt (1989), Checkland (1981), Checkland and Scholes (1999), Eden and Ackermann (1998), Flood (1999) and Vennix (1996).

Nutt (1989) also identifies an aversion, by managers, to analytical [probability-based] techniques. Seemingly, they seek to avoid ambiguity and uncertainty.

f. <u>*Societal constraints*</u>*. Social, organisational, and political constraints and capabilities, as well as technological ones, are central both to the feasibility and the desirability of solutions.*

Of particular interest here are ‘systems of meaning’ described by Flood (1999) and the works of Vennix (1996) and Eden and Ackerman (1998). Sterman (1994) makes the important point that the best technical or logical solution is unacceptable if not trusted by stakeholders, or if not politically viable.

5.15 Summary – Chapter 5

An appreciation of the nature of wicked problems is essential before we can develop meaningful and effective ways of addressing them. So, in this chapter, ‘wicked’ problems were characterised. This characterisation built on that which already existed in the literature. Observations from case studies in earlier chapters were used to expand on existing characterisations. This was necessary because of the more extensive descriptions of the nature of complexity both in the literature and derived from the case studies. This detailed characterisation should aid us in development of our principles of method for addressing wicked problems.

5.16 Significant Contributions Made in Chapter 5

An expanded characterisation of tame and wicked problem is developed on the basis of empirical case studies and an extensive literature review. This is used to help explain alternatives for addressing such problems including advantages and disadvantages of these alternative methods.

CHAPTER 6: PRINCIPLES OF METHOD AND FRAMEWORK FOR ADDRESSING ‘WICKED’ PROBLEMS

Synopsis

The class of problems investigated in Chapters 3 and 4, and characterised in Chapter 5, present decision-makers with uncertainty, ambiguity and conflict. Given our definition and descriptions of these problems, we still need to determine how to develop effective remedial strategies to deal with them. Pioneers in this field of endeavour have known from the beginning that these problems can respond in counter-intuitive ways to our remedial efforts. Because these problems easily exceed human cognitive capabilities and confound our intuition and judgement, we need help. Analysis of complex feedback dynamics and augmentation of naturalistic mental simulation of strategies through system dynamics modelling offers considerable promise.

Based on analysis of preceding chapters and the literature review, this Chapter outlines the principles of method for addressing ‘wicked’ problems. A new framework, of Iterative and Interactive Strategy Development (IISD), is proposed within which the building of qualitative and, if needed, quantitative system dynamics models follows detailed problem analysis through a joint effort by decision-maker and analyst. IISD sets out to focus on: tactics to bring about better understanding; identifying and structuring the ‘right’ problem; analysing the effects alternate strategies might have; and how to develop consensus and commitment to enact a chosen strategy. Developing a commitment to act is considered a key outcome, given the lack of response to environmental cues, and lack of action by managers apparent, in the cases studied.

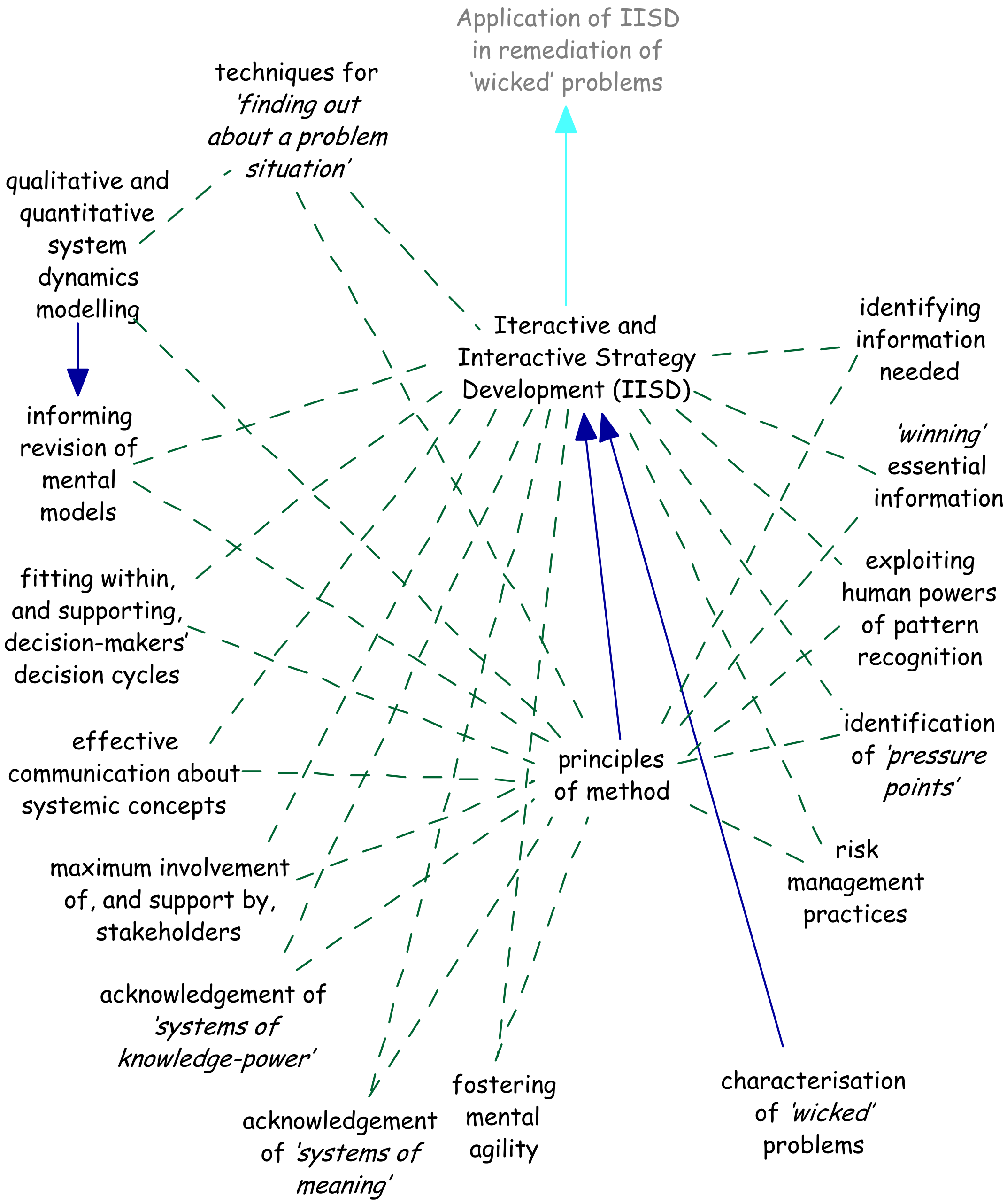


Figure 6-1. Concept Map - Chapter 6 Synopsis

Note:

1. Concepts shown in black text are contained in this chapter.

The preceding chapters showed that when we set out to design decision-support systems, we have to consider many things. These include the risks of addressing the wrong problem, or addressing the right problem and producing a workable strategy that is never implemented. We have to cater for human cognitive limitations, cognitive behaviour, assumptions, prejudices and bias. Any successful problem-solving methodology we devise cannot be divorced from considerations of the way people think and feel, the way they have learned to build schemata, their prior experience, and their current assumptions about the problem situation. We have to find ways of capitalising on human cognitive strengths. We have to develop allegiances with key stakeholders and gatekeepers. We have to develop highly effective communications. Problem conceptualisation, analysis, strategy development and implementation must occur within the time required.

6.1 Reliance on Stakeholder's Views

It is an unrealistic expectation, even given what we now know, to walk straight in and solve 'wicked' problems. Our starting position involves relying heavily on stakeholders' views of a particular problem or issue. Doyle and Ford (1998: 3-29) argue that stakeholder views are almost always incomplete, fuzzy, linked to ingrained assumptions or involve imperfect knowledge, yet those views frequently form the basis for building models. Their observation suggests the need for research into how we define, elicit and exploit the thinking, the mental models, of those who face the problems, especially if we are to use that information in the formulation of models for strategy development, or in decision-support.

In developing decision-support we continually call upon the client's opinion and perspective to help in the definition of business rules that become the building blocks of our conceptual or analytical models. Indeed, at 2.2, a strong case was put for maximum stakeholder involvement. Our reliance on the client's view may be heaviest when dealing with 'soft' variables, those that are not easily quantifiable, or during the conceptualisation phase of our problem-solving intervention. In the conceptualisation phase we rely heavily on the client's view, as correct or incorrect as that may be, until we can formulate and validate our own views. The fundamental importance of problem conceptualisation was argued at 2.1.

As we proceed through conceptualisation to quantitative analysis, we make many choices:

a. Where do the boundaries of the problem space lie?

b. Where should we draw the boundaries to the solution space? What are the limits to what we include or exclude from our analysis?

c. What parameters influence the observed behaviour, and to what extent?

d. Do we include all identified parameters? If not, which ones do we exclude? Which ones do we include?

e. Is it appropriate to combine parameters by addition, multiplication, or other operations?

f. Where a model is built, is the model behaviour a sufficient replication of observed real-world behaviour?

g. Should we stop model development at this point, or continue?

Some choices are those of the modeller alone, but many are informed by the client's view. Both client and modeller are involved in ongoing rounds of choice and decision-making. This is particularly the case in action research, or group model building. Just as modelling is an iterative process (Homer, 1996) that involves building, repeatedly running and making adjustments to the model, iterations of choice and decision-making continue through every stage. Just how good those choices and decisions are, see 5.5, dictates the veracity of the modelling and, ultimately, the intervention.

Given the potential impact of individual perspectives and stake holdings, it is at least intuitively obvious that the formative stages of decision-making cannot be trivialised without risk of basing decisions on invalid, biased assumptions or inappropriate problem conceptualisation. This conceptualisation process, and subsequent analysis must compensate for the human cognitive limitations identified in 2.5 - 2. 11. System dynamics offers the necessary analytical support and compensation for human limitations when dealing with dynamic complexity. Given ready access to powerful desktop computing, it seems we are now well equipped to support conceptualisation and analysis of complex problems. However, we need to be vigilant that just because we are building computer models and running simulations we are solving real problems, and building valid insights. The literature contains many claims about the efficacy of modelling, dynamic simulation, and management flight simulators as aids to providing insights into dynamic problem behaviour. An example of a typical claim is described in 6.2, below.

6.2 Clever Illusion or Unintended Revelation

Recently, a professional colleague excitedly demonstrated a computer simulation intended, in the context of a hypothetical corporation, to make executive managers aware of the pitfalls of their decision-making and business strategy development practices. In the game, executives are required to manage the corporation through major organisational change.

A management ‘flight simulator’ interface is presented to the player. This interface appears as a graphical control panel with gauges, switches, and buttons. The health of the business is monitored continuously and presented via the interface. At quarterly intervals, the player can change a selection of parameters as he implements his evolving strategies. The game can be run as often as the player wishes. Different strategies can be trialed, results observed and the effectiveness of management key performance indicators (KPIs) gauged. Information feedback comes from relevant parts of the company via written reports, memos, and e-mails.

Invariably, despite the application of intuition and judgement, the corporation crashes out of control within 8-10 quarters. New strategies the player might try eventually fail, it is only the time to failure that varies. As the demonstration progresses through subsequent iterations, the player is inexorably drawn to the realisation that he doesn’t really understand how the corporation should be managed. It becomes clear that he does not understand the mechanisms which produce dynamic variations in the market place and how, in turn, the market-place reacts to the combined effects of recent strategies and manifestation of delayed effects of earlier ones. The game ends with the anticipated outcome that the player calls *Business Dynamics Consulting Group Inc.*, a fictitious company, to assist in the development of suitable, dynamically resilient business strategies.

The demonstration is contrived. It is a clever marketing trick. In many ways it is similar to the Beer Game® which is widely used to introduce students to system dynamics modelling. Both this demonstration and the Beer Game® exploit what Kleinmuntz (1993) recognised about decision-making in dynamic environments... such decision-making is only reliable when there is juxtaposition of previous decisions and observed feedback effects:

> … Diehl (1992) examined decision rules in a very simple inventory management task. Diehl varied both the length of the delay and the complexity of feedback structure. Performance was most effective with simple, undelayed feedback structure. As both delays and complexity increased, performance deteriorated… (Kleinmuntz, 1993: 226).

This is the 'misperception of feedback' described by Sterman (1989a; 1989b; and 1989c.) and by Kleinmuntz (1993) as the 'misperception of the *implications* of feedback'. See 2.11 and 2.12. As a player in the game one is presented with a mass of information. This serves to mask, even further, what underlies dynamic behaviour. Systemic response to player's remedial strategies is counter-intuitive. Despite having the opportunity to play the game over and over, there is little chance that any player can uncover the complex set of interrelationships and underlying operating mechanisms that produce the observed responses. Instead, one is forced to rely on extant decision heuristics. Unfortunately, in this context, the heuristics in the player's adaptive toolbox do not have high *ecological validity*. Ecological validity describes the situation where recognition-primed decision making, based on relevant heuristics is highly effective in a specific environment. See Figure 2-6. Adapting to new cues in the contrived environment is difficult because much of the behaviour being observed at any time, in part at least, is the product of earlier attempts at corrective action. In all cases, the observed behaviour is the product of mechanisms masked from the player. In this demonstration, the designers deliberately mask the underlying mechanisms: in real-world problems they are just as effectively masked from our view, albeit rarely by design.

Apparently, many decision-makers believe they can sit at the control panel, monitor the changing patterns displayed by the dials, gauges and lights, and then pull the levers and flick the switches to make the necessary adjustments ranging from minor trim to major strategic change.

The pilot of a Boeing 747 might be trained on a cockpit simulator, but only commences such training after studying aerodynamics and developing a detailed understanding of how an aircraft behaves under a wide range of dynamic conditions. A teenager might learn to fly the same 747 simulator drawing heavily on coordination skills and heuristics developed on a Sony® Playstation, or in an amusement arcade. There is risk that our juvenile 'pilot', having successfully flown the simulator for a period of time, assumes he has developed a sufficient understanding of dynamic behaviour. Without a real understanding of aerodynamics, it would only be a matter of time before the teenager, placed at the controls of a real 747, crashed. Considerations of risks, particularly the risk of not really understanding what produces dynamic behaviour must be included in our principles of method. Also see 2.13, 4.9 and 4.10.

6.3 Role of Management Teams in Addressing Strategic Problems

All organisations, regardless of their size and nature of their business must have effective ways of addressing strategic problems. In large, modern organisations the executive function is likely to be performed by a team who are responsible for addressing strategic problems and setting corporate objectives. Disagreement is likely regarding existence of a problem, whether it needs to be addressed and, if so, how. See 1.2 and 1.5. Once a decision has been taken to address a problem, developing an appropriate strategy is one thing, implementing it can be something quite different. See 2.25-2.27 and 7.8. The organisation's executives, the nominal decision-makers, may develop a strategy but, without their cooperation, others may ultimately determine in what form it will be implemented, if at all.

6.4 Principles of Method – Initial View

We have characterised the nature of wicked problems, examined how decision-makers think, considered human cognitive limitations in regard to dynamic decision-making, the role of stakeholders and gatekeepers, and the extant state of systems thinking and system dynamics practice. It is now possible to enunciate a set of principles of method we might apply in addressing wicked problems. In outline, the principles of method are:

a. Because some information will be hidden, ambiguous, compartmentalised, or deliberately withheld, or access controlled, see 2.2, 2.15, 2.25-2.27, 4.9 and 5.2, we need highly effective ways of:

   (1) identifying what information might be needed; and

   (2) *winning the essential information*. See 2.3 and 2.4.

b. Because systemic behaviour is determined by problem structure, we need tools and techniques that enable *information processing* in ways that facilitate *pattern recognition*, see 2.19 and Figure 2-4, and identification of *underlying systemic structures*, Figures 3-7, 4-5, 4-6 and 4-7, that is, identification of:

(1) the relevant feedback and delay mechanisms;

(2) feedback mechanisms which currently dominate, and the mechanisms producing that dominance;

(3) how feedback dominance might change with changing circumstances; and

(4) *pressure points* to which management effort might be applied. See 3.12 and 3.13.

c. We need to assure the maintenance of effective *communications* as we navigate our way through the *Decision Cycle*. See 2.20.

d. At every step, we need to build understanding with the aim of:

(1) revising mental models in ways that are:

(a) accurate,

(b) timely, and

(c) relevant.

(2) providing validation and adjustment, as necessary, of decision-makers' *systems of meaning*, see 2.17;

(3) enabling *mental agility*, see 2.23;

(4) informing *decision-making*, see 2.19; and

(5) leading to commitment to take *action*.

e. *Involving stakeholders and gatekeepers* as fully as their busy schedules allow, see 2.2, remaining cognisant of the influence, or direct control, they can exert.

f. Incorporation of sound *risk management* practices, see 4.9 and 4.10. noting:

(1) effort applied must be commensurate with benefits that might flow; and

(2) risk management can only be effective when risks are well understood;

g. Focus on *learning*, see 1.3 and 1.7, which should:

(1) be *generative*;

(2) be *planned*; and

(3) enable decision-makers to *learn their way into an unknowable future*. See 2.22 - 2.24 and 2.28.

6.5 Application of Methodology

The methodology might follow this sequence, noting factors that militate against effective decision-making identified at 2.25 – 2.27:

a. Identify individual concepts, which operate within the problem space and within the minds of stakeholders.

b. Classify each of the causal, connotative, and conflict relationships.

c. Map the causality using appropriate tools and level of aggregation.

d. Depict causal relationships and structures through a series of models. The influence diagramming approach described by Coyle (1996) is strongly advocated because of its rigour. See 7.13.

e. Verify, progressively develop, and validate models. As far as possible, involve decision-makers closest to, or who have greatest stake, in the problem at hand.

f. Where dynamic simulation models are built, give key stakeholders opportunities to play, or at least witness, the simulations. Simulations should be run repeatedly until confidence is gained in the model's fidelity.

g. Use models as test-beds for building, understanding, and trialing strategies before real-world implementation.

6.6 Stakeholder Influence

The stakeholders in a problem, or the strategy proposed to overcome it, can be diverse. It may be difficult to identify who they are and the extent of their claims. Further, for some stakeholders, the fact that a problem is being addressed and that a change in the *status quo* is likely to follow can create anxiety, the manifestations of which may be more unsavoury than the extant problem. See 2.2, 2.3, 2.26, and 6.1.

All stakeholders exert influence: the extent to which they do depends on their position, vested interests, politics, or ambition. One category of stakeholder is considerably more influential than others. They are gatekeepers, vital to successful strategy implementation. Failing to acknowledge or accommodate gatekeepers may create insidious resistance to strategy implementation.

6.7 Unavoidable Complexity

Strategic issues can be exceedingly complex. See 1.3 - 1.5. This is a fact some decision-makers would prefer to ignore. See 2.9. Although complexity pervades virtually every aspect of life we all tend to ignore it, instead opting for simplified views that make decision making easier and our lives less complicated.

A fundamental consideration in decision research is whether or not an apparently simplified approach we observe being employed to solve a problem is carefully crafted on the basis of experience and knowledge, see 2.5 - 2.11, or inappropriately based on over-simplification, intuition, bias, or habit. A doctor, for example, may choose to treat familiar symptoms without ordering a series of tests to determine the root cause of an illness. What may not be clear is the extent to which experience and knowledge have been applied and how risk to the patient was assessed. See 2.15.

6.8 Decisions Made in a Complex Environment

There is little room for over-simplification, intuition, bias, habit or other inappropriate decision practices in medical diagnosis. Such is unacceptable. Poor decision practices are equally unacceptable in managerial situations where consequences are significant. Nutt (1989) observes after researching decision-making and decision practices over a period of some 20 years that, when dealing with highly complex and dynamic situations, decision-makers repeatedly employ inappropriate decision practices. It is argued that managers and decision-makers could well do better, particularly given access to the tools and techniques described in this dissertation.

6.9 Avoiding 'Bad' Decisions

Complex real-world problems often defy intuition. Human judgement can be totally ineffective. Learning about the true nature of problems often does not occur, and we habitually fall into the traps of making 'bad decisions'. Nutt (1989) suggests we should avoid decision processes, which are poorly managed, skip important steps or involve superficial treatment. Causes of 'bad decisions' include (Nutt, 1989: 26-46):

a. addressing the wrong problem;

b. failing to use participation;

c. being distracted by conspicuous options;

d. overreacting to time pressure and stress;

e. overusing intuition and judgement;

f. using dogmatic decision practices;

g. failing to deal with values;

h. problems in making subjective estimates;

i. failing to use analysis;

j. problems in communicating analytical results, and

k. failing to learn.

6.10 Making the Most of Cognitive Capability

Despite cognitive shortcomings outlined at 2.18, we still have impressive strengths, such as powers of pattern recognition, which we should exploit as far as we can. See 2.19. Strategic problem analysis involves careful consideration of delays and counter-intuitive behaviour, unlike riding a bicycle where the same inputs under the same conditions faithfully produce predictable and repeatable results, within a timeframe where cause and effect can be readily correlated by the human brain. By studying the dynamics and focussing on behaviour over time: periods of increase and decrease, phase relationships among variables, peaks and valleys, and so on, we can isolate pattens amenable to analysis by system dynamics modelling (Richardson and Pugh, 1981: 19). Once recognised and isolated, dominant patterns of behaviour can be replicated in our models as we build, experiment and learn. This is the heart of system dynamics modelling approach, one that allows us to make the most of our cognitive capability.

6.11 System Dynamics Modelling - Key to Understanding

System dynamics is a tool intended to enable our thinking about how feedback, delay, loop dominance, and non-linearity contribute to systemic behaviour. System dynamics is a methodology embedded in the cybernetic or control paradigm, that is the 'branch of control theory which deals with socio-economic systems' (Coyle, 1977). Wolstenholme defines system dynamics as:

> A rigorous method for qualitative description, exploration and analysis of complex systems in terms of their processes, information, organisational boundaries and strategies; which facilitates quantitative simulation modelling and analysis for the design of system structure and control (Wolstenholme, 1990: 3).

Qualitative System Dynamics	**Quantitative System Dynamics**	
(Diagram construction and analysis phase)	(Simulation phase) *stage 1*	*stage 2*
To create and examine feedback loop structure using resource flows, represented by level and rate variables and information flows, represented by auxiliary variables. To provide qualitative assessment of the relationship between system processes (including delays), information, organisational boundaries and strategy. To estimate system behaviour and to postulate strategy design change to improve behaviour.	To examine the quantitative behaviour of all system variables over time. To examine the validity and sensitivity of system behaviour to changes in: (i) information structure (ii) strategies (iii) delays / uncertainties.	To design alternative system structures and control strategies based on: (i) intuitive ideas (ii) control theory analogies (iii) control theory algorithms in terms of non-optimising robust policy design. To optimise the behaviour of specific system variables.

Table 6-1. System Dynamics – A Subject Summary (1)(2)

Notes:

1. Although the steps of the approach are given as sequential, the method in practice, both within and between phases and stages is and iterative procedure (Wolstenholme, 1990: 4).
2. The relationship between qualitative and quantitative techniques is further described under the heading 'Where Qualitative and Quantitative Methods Fit – An Overview', at 6.27.

Qualitative System Dynamics

This phase of the method is based on creating cause and effect diagrams or system maps (known as causal loop or influence diagrams) according to precise and rigorous rules and using these to explore and analyse the system. These diagrams are developed with system actors to allow their mental models concerning system structure and strategies (and those of the environment of the system) to be made explicit. The word structure refers to the process and information structure of the system and is referred to as the information feedback structure of the system. Hence System Dynamics models are often described as taking a feedback perspective of a situation. It is an underlying premise of the subject of System Dynamics that the feedback structure of a system is a direct determinant of its behaviour over time.

The diagrams create a forum for translating barely perceived thoughts and assumptions about the system by individual actors into useable ideas which can be communicated to others. The intention is to broaden the understanding of each person and, by sharing their perceptions to make them aware of the system as a whole and their role within it; that is, to provide an holistic appreciation…

Once created, the diagrams can be used to qualitatively explore alternative structure and strategies, both within the system and its environment, which might benefit the system. Although comprehensive simulation is not advocated by the method at this stage, it is possible from the study of the feedback loop structure of the diagrams, to estimate their likely general direction of behaviour (say growth or decline). Further, by using some of the experiences from the results of quantitative simulation modelling in other systems it is possible to apply guidelines for the redesign of system structures and strategies to improve system behaviour (Wolstenholme, 1990: 4-5).

Quantitative System Dynamics

The second phase of the subject is that of quantitative computer simulation modelling using purpose built software. This is the more conventional and traditional phase of System Dynamics and involves deriving with system actors the shape of relationships between all variables within the diagrams, the calibration of parameters and the construction of simulation equations and experiments. Although numbers are attached to variables during this phase, it should be stressed that the method is not aimed at accurate prediction or solutions. It is more concerned with the shape of change over time. Accurate prediction on the basis of past performance, assumes that the structure and strategies of the future will not be too dissimilar from the past. If the purpose of the model is to redesign structure and strategies, prediction must, by definition, be less accurate. Emphasis is on the *process* of modelling as a means of improving understanding. The idea being that such understanding will change

> perceptions and add to the ability of the system actors to react better to future problems, that is, to make them more self-sufficient as problem solvers.
>
> The power of quantitative System Dynamics has been significantly enhanced in recent years by the development of the desk-top computer and associated software. The creation of computer simulations of dynamic models has always been a significant factor in improving systemic understanding. This is because there is a severe limit in the cognitive ability of the human brain to process multi-variate problems without such help (Wolstenholme, 1990: 5-6).

Infrequently, dynamic problems are found to contain chaotic modes. See 5.6. This raises concern that the problem modelled is complex, chaotic, or the model faulty. The last can be obviated by model-building practices built on application of the scientific method (Homer, 1996). Comprehensive testing is needed to build confidence in model behaviour over the full range of parametric values (Balas and Carpenter, 1990; Coyle and Exelby, 2000; Forrester, 1961; Forrester and Senge, 1980). Sterman (2000: 846-853) notes that it is not possible to validate models in order to establish truth in an absolute way. Despite this, the extensive system dynamics body of knowledge is considered and robust. It is assumed to be sufficiently robust for the purposes of the investigation of its integration with qualitative modelling. To demonstrate the efficacy of quantitative system dynamics in diverse circumstances is beyond the scope of this dissertation.

The goal of a modelling effort is to improve understandings of the relationships between feedback structure and dynamic behaviour of a system, so that policies for improving problematic behaviour may be developed (Richardson and Pugh, 1981: 38-39). See Figure 6-2.

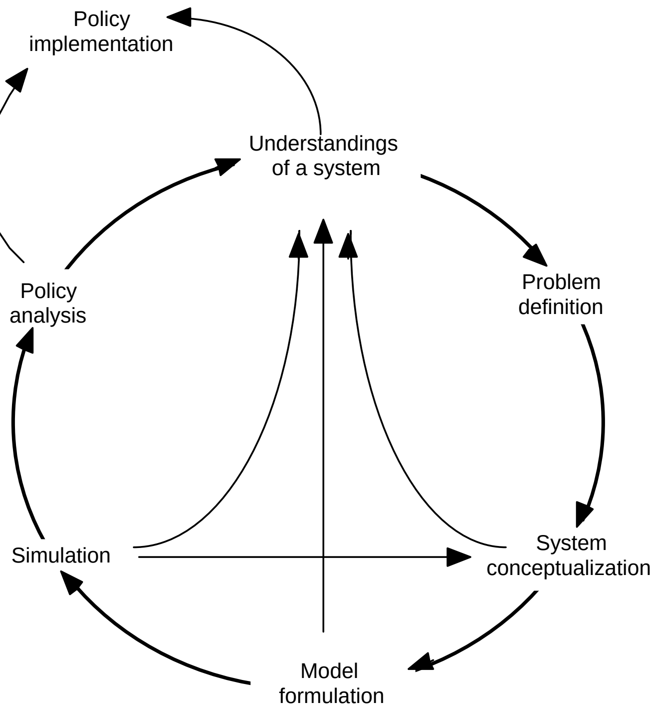


Figure 6-2. Overview of the System Dynamics Modelling Approach (1)

Note:

1. After Richardson and Pugh (1981: 17).

System dynamics modelling allows us to analyse systemic structure, feedback and delay mechanisms that produce counter-intuitive behaviour that often defies our strategic decision-making efforts. Modelling is a never-ending process. See 5.7. We build, revise, compare and change, and with each cycle our understanding improves. Simulation provides a graphic vehicle for demonstrating dynamic behaviour of systems that would otherwise be far beyond our ability to visualise; thus modelling and simulation can be powerful tools to aid learning. System dynamics modelling also provides a vehicle for simulating the effects of changing policy. It facilitates evaluation of alternate strategies in a benign environment before foisting them upon a world where consequences might be both dire and irreversible.

6.12 Patterns of Behaviour and Creative Ideas in Strategy Development

Recognising symptoms is a crucial part of diagnosing complex systems, and the human brain is particularly strong in pattern recognition. See 2.19 and 6.10. However, recognition is strongly context dependent. When appropriate contexts are created, recognition of patterns is greatly enhanced, and creative ideas are likely to be generated. Creative ideas lead to alternate strategies requiring evaluation. System dynamics, qualitative and/or quantitative, is used to discriminate among alternate strategies by exploring model sensitivity, dominant feedback mechanisms, and pressure points. How this is done is explained in detail at Chapters 7 and 11.

6.13 Effective Strategic Problem Solving

An effective strategic problem solving methodology should:

a. involve executive decision makers as fully as their busy schedules will allow, noting their role in championing organisational change interventions and leading the organisation through implementation of chosen strategies;

b. recognise shortcomings of, and resistance to, formal analytical methods;

c. exploit differences in opinion with a view to challenging implicit assumptions and preventing premature problem definition;

d. acknowledge the roles of stakeholders and gatekeepers and monitor their influence, particularly to avoid resistance to change or to strategy implementation;

e. recognise the inherent complexity and systemic nature of strategic problems and human cognitive limitations in respect of these problems;

f. avoid inappropriate decision practices and 'bad decisions' through vigilance, and employment of carefully formulated analytical methods;

g. remain cognisant of counter-intuitive behaviour of dynamic systems;

h. recognise the strength of human learning ability given appropriate conditions;

i. make the most of cognitive capability by recognising how tools such as system dynamics modelling can make up for human cognitive deficiencies;

j. build on human ability to recognise patterns of behaviour and develop creative ideas;

k. build on proven system dynamics techniques of investigating dominant mechanisms and pressure points; and

l. build on strengths of both soft and hard analysis methods.

6.14 Integrating Soft and Hard Systems Analysis

Systems thinking and system dynamics literature contains myriad examples of discrete applications of specialist tools and techniques, and arguments about their veracity. However, there have been few serious attempts to integrate these tools and techniques and make them broadly applicable. Further, there is strong evidence of disillusionment of decision-makers with narrowly focussed, specialised traditional operations research techniques. The need to step back from parochial arguments and to focus on integrating soft and hard systems analysis is quite evident in the literature (Forrester, 1994; Rosenhead, 1989).

A recent and refreshing account of successful integration of soft operations research and system dynamics techniques is contained in Ackermann, Eden, and Williams (1997). Cognitive Mapping (Eden, 1988) was initially used to support interviews with the client when the scope and nature of the problem were being established. It was then used throughout to record perceptions of the interrelationships between factors affecting the problem. Ackermann, Eden and Williams employed a progressive mixing of qualitative modelling (large cognitive maps) with influence models and system dynamics modelling and simulation to enhance learning, understanding and making a complex legal case defensible. It is most interesting to note the iterative and interactive framework in which soft operations research and system dynamics modelling and simulation were integrated; cycling between modelling approaches gave benefits that could not have been attained by either hard or soft modelling in isolation. Whilst their paper describes the process, it only does so in outline, only. Ackermann, Eden, and Williams explain that their approach involved capturing then analysing mental models of those with relevant knowledge, experience and perception of the problem at hand.

Senge explains:

> …the discipline of working with mental models starts with turning the mirror inward; learning to unearth our internal pictures of the world, to bring them to the surface and hold them rigorously to scrutiny … it also includes the ability to carry on “learningful” conversations that balance inquiry and advocacy, where people expose their own thinking effectively and make that thinking open to the influence of others. (Senge 1990: 9).

When attempting to exploit mental models, it is important to note that some individuals may feel threatened by the idea of being subjected to processes, which expose what they really think. See 2.3 and Figure 2-3. This is understandable given that the way people think and behave is the product of years of conditioning. Open, honest, non-threatening, and sensitive ways of elicitation are necessary. Cognitive and concept mapping can be powerful tools for facilitating access to what people really think, and for building understanding shared among stakeholders, gatekeepers, analysts and decision-makers. See 7.7 - 7.12.

Ackermann, Eden, and Williams produced a series of individual (cognitive) and group (concept) maps in order to create influence diagrams of the complexity inherent in the Channel Tunnel Project. See Figure 6-3.

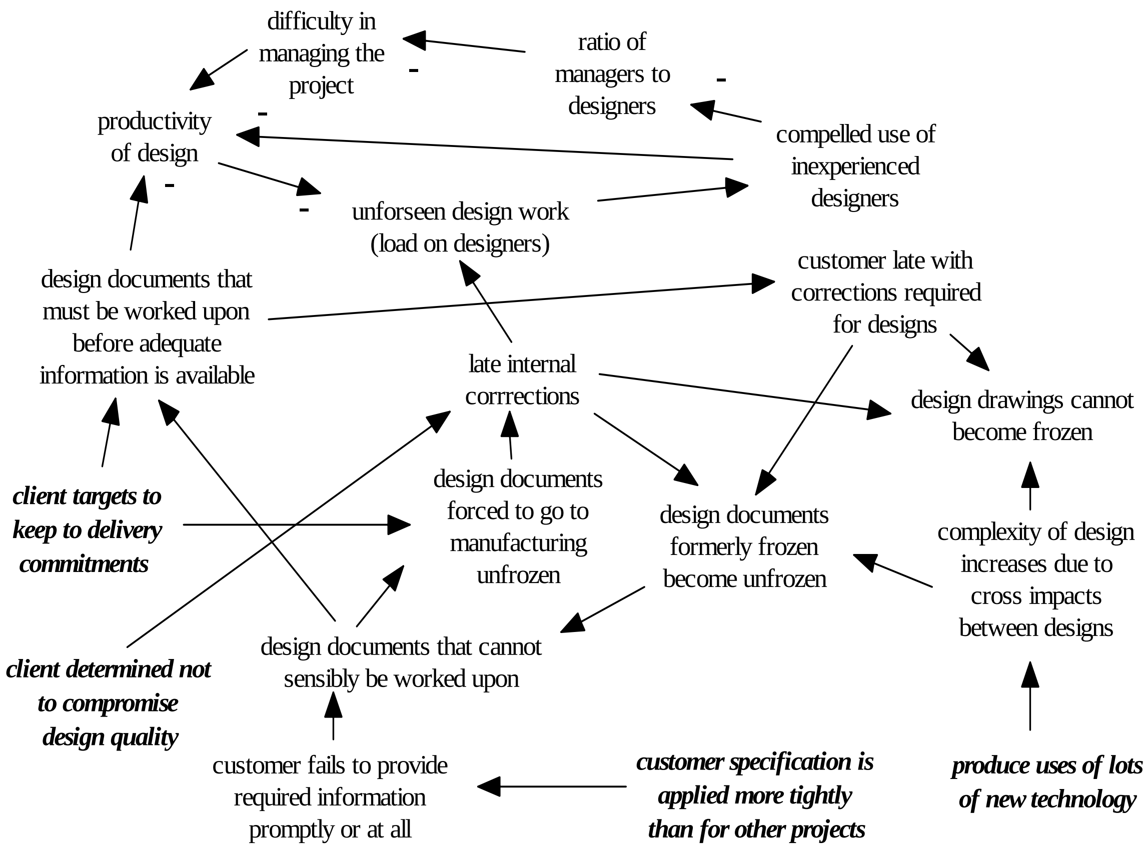


Figure 6-3. Influence Diagram Produced From Cognitive Maps (1)

Note:

1. Ackermann, Eden and Williams (1997: 52).

Ackermann, Eden, and Williams explain that building cognitive maps then developing influence diagrams of interrelationships in this complex project were effective in aiding the client, barristers and solicitors to develop an understanding sufficient to build a case sound enough to be placed before the courts. Note that in Figure 6-3 concepts shown, in bold italics, show influences of particular importance to the legal case. Iterative and Interactive Strategy Development (IISD), described in this chapter, builds on work by Ackermann, Eden and Williams (1997) and the basic system dynamics modelling approach founded by Forrester (1961).

6.15 Iterative and Interactive Strategy Development - Overview

A variety of techniques may be integrated into IISD, depending on the nature of the problem and the needs of the client. Tools and techniques typically encompass soft operations research, systems thinking, and system dynamics modelling in a multi-disciplinary approach. IISD is shown diagrammatically at Figure 6-6.

6.16 Where Qualitative and Quantitative Methods Fit – An Overview

Qualitative analysis plays an important role in 'finding out about a problem situation', Figure 2-9, and establishing the basis for subsequent quantitative analysis. Activities that take place between recognition of 'we have a problem here… ', explicit definition of the problem space, and a general description of the likely solution space are known as conceptualisation. Figure 6- 7, below, depicts the author's view of the relationship between qualitative and quantitative analysis, tools, techniques and products from the various activities.

6.16.1 Systems Thinking and Other Intellectual Devices. Various intellectual devices are used to facilitate thinking, communication, dialogue, discussion, and surface assumptions about systemic problem situations. These devices assist in problem conceptualisation, initial problem investigation, problem definition and analysis of the associated problem spaces within which problems exist.

By way of example of the use of these devices, researchers and practitioners from 22 countries presented 110 papers and keynote addresses at the 2000 International Conference on Systems Thinking in Management (ICSTM 2000) held at Deakin University, Deakin, Victoria, Australia in November 2000:

a. Approximately 50% used some form of directed graph, causal loop diagram, influence diagram, or concept map to explain systemic issues or to communicate ideas. The use of these devices spanned almost all countries represented. Causal loop diagrams were most prevalent.

b. Approximately 18% of the papers described developments in the application of SSM, see 2.28. Many papers or presentations included examples of rich pictures. SSM has developed over a period of more than thirty years and has proven to be most popular in UK, Australia and New Zealand, each of which contributed approximately 5%. Approximately 1% originated in each of The Netherlands, Turkey, and USA.

Devices similar to cognitive mapping include those, which cluster or map interrelationships between linked concepts. These include:

a. Hexagons (Hodgson).

b. Causal Loop Diagrams (Senge, Kim).

c. Oval Mapping Technique (Eden and Ackermann)

These will not be treated separately. However, there is a proliferation of computer tools to aid conceptualisation. The issue here is not that these tools exist, but that to use them effectively requires systemic thinking. Other devices include traditional soft operations research techniques such as Delphi, Morphological Analysis, Synectics and Brainstorming. The main outputs are:

a. preliminary definition of the boundaries to problem space; and

b. preliminary definition of the problem. (including the potential solution space).

6.16.2 Preliminary Systems Analysis. Preliminary systems analysis follows that traditionally applied by Forrester (1961) and described by Richardson and Pugh (1981). In essence, this involves graphing of reference modes of observed behaviour. The main outputs are:

a. definitions of the reference modes of behaviour which become the basis for development of subsequent quantitative models; and

b. refinement of the definition of the potential solution space.

6.16.3 Qualitative Modelling. See 6.11. Qualitative modelling techniques generally do not differentiate between:

a. stocks or levels;

b. rates or flows;

c. policy inputs; and

d. parametric unit dimensions.

This is problematic, and is addressed at 11.10. An exception is influence diagramming as advocated by Coyle (1996).

6.16.4 Quantitative System Dynamics Modelling. See 6.11. Application of quantitative system dynamics modelling and simulation is described in detail at Chapter 7. The main outputs of quantitative modelling are:

a. insights regarding dynamic behaviour modes and how these are produced; and

b. remedial strategies to address complex, dynamic, systemic problems.

There is not a seamless transition across the four levels in the framework depicted in Figure 6-4. Rather, choices regarding tools and techniques to be applied in a given situation are determined by familiarity and expertise of analysts. To a lesser extent, preferences of the client are considered. For example, where the client organisation is comfortable with drawing and using pictures to facilitate communications about the complexity of human affairs, SSM would be appropriate. SSM, for example, finds widespread use in developing requirements for information technology interventions (ICTSM 2000). Causal loop diagrams are the systems thinking tool of choice for many, despite their limitations. See 11.3 and 11.4.

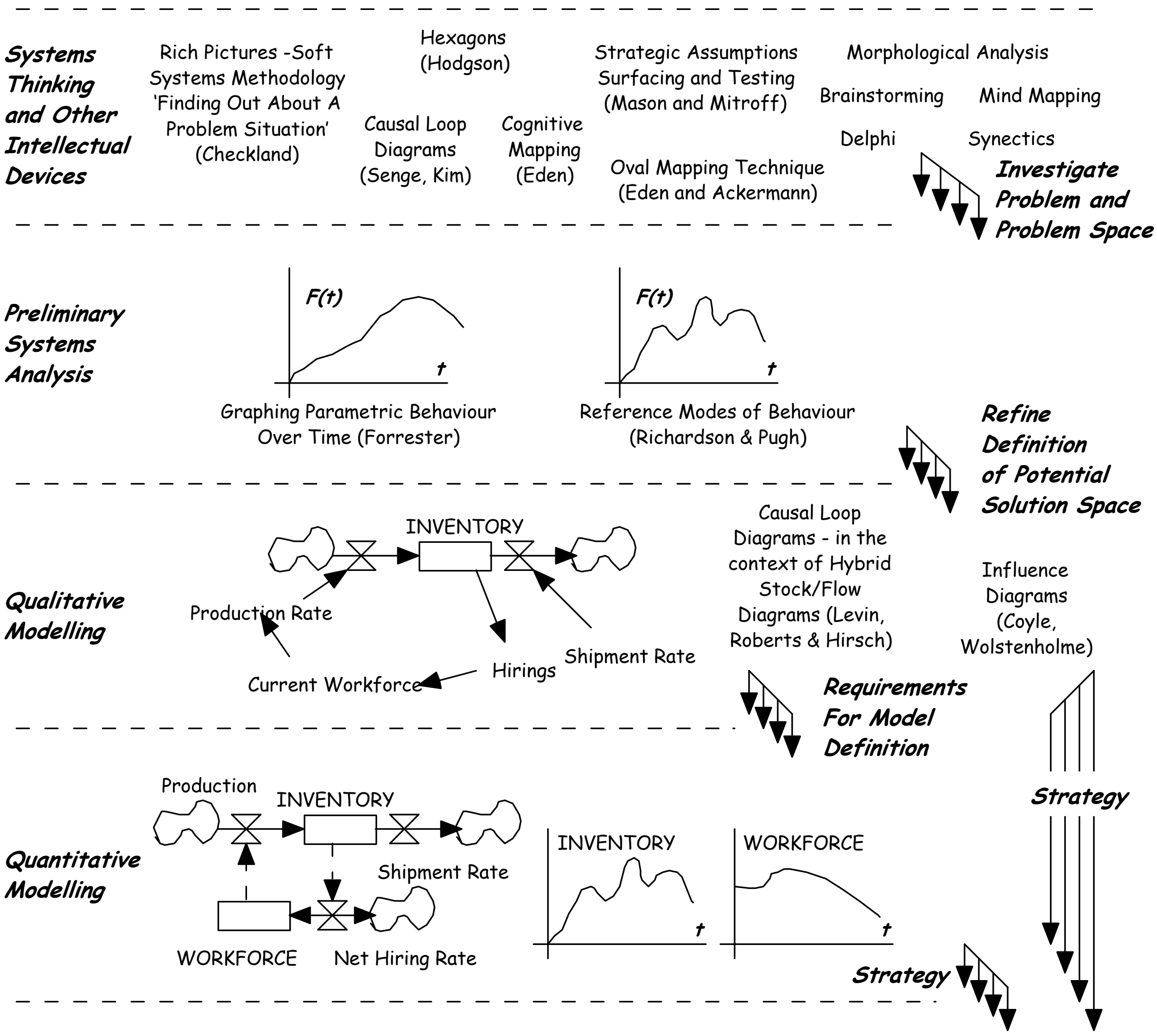


Figure 6-4. General Framework Integrating Qualitative and Quantitative Modelling (1)(2)(3)

Notes:

1. The list of intellectual devices that might be used to enable creative systems thinking and to elicit knowledge or perspectives of the perceived problem is not intended to be exhaustive. Also see 'Problem Conceptualisation Techniques', below.

2. The delineation between activities is not necessarily clear. Practitioners can approach problem solving in quite different ways. There are no standard protocols for conducting either qualitative or quantitative modelling activities.

3. The *problem sensing – problem conceptualisation – analysis – strategy development – implementation – monitoring* process and activities within that process are incremental and iterative (Homer, 1996: 1-19; Mason and Mitroff, 1981: 21-24; Nutt, 1989: 36; Sterman, 2000: 86-89; Van Gundy, 1992: 17-24).

6.17 Group Model Building – Involving Qualitative and / or Quantitative Techniques

Recognition of the critical roles of stakeholders and gatekeepers, see 2.2, draws us inexorably toward group problem solving as a principle rather than a technique. Also see Chapter 7. In their 1999 review of the efficacy of group model building, Rouwette, Vennix, and van Mullekom, make the important observation that since the inception of system dynamics in the second half of the 1950s, the implementation of results and system improvement have been its foremost goals. Close involvement of the client is one way of enhancing the likelihood of implementation. As noted earlier, Lewin considered gatekeeper involvement essential if organisational change was to succeed (Weisbord, 1987: 88-91). This remains the case regardless of the organisational change intervention employed, whether it is the product of systems thinking, qualitative system dynamics, or quantitative system dynamics analysis.

Rouwette, Vennix, and van Mullekom (1999) identify a number of group modelling approaches, employing qualitative or quantitative techniques, or a mix of both:

a. Reference Group Approach (Randers, 1977).

b. Strategic Forum (Richmond, 1987; 1997).

c. Stepwise Approach (Wolstenholme, 1992).

d. Participative Policy Modelling (Verberg, 1994; Vennix, 1996).

e. Modelling as learning (Lane, 1992).

f. Approaches incorporating elements of:

   (1) SSM (Sancar, 1987; Bentham and De Visscher, 1994).

   (2) Cognitive mapping (White, Ackroyd and Blakeborough, 1994).

g. Group Model Building (Richardson and Andersen, 1995; Vennix, 1996; Huz, Andersen, Richardson and Boothroyd, 1997).

Richardson and Andersen (1995) make the distinction that group model building, as they intend the phrase, signals the intent to involve a relatively large client group in the process of model formulation, not just conceptualisation. The goals are:

a. wider resource base for insightful model structure,

b. extended group ownership of the formal model and its applications, and

c. acceleration of the process of model building for group decision support (Richardson and Andersen, 1995: 113).

6.18 Problem Conceptualisation Techniques

Their definition of the term group model building is accepted for the purpose of this thesis, noting that there are many group conceptualisation techniques, such as those listed below. This list is derived primarily from Rosenhead (1989). These are marked with an asterisk (*). Also referenced are other locations where descriptions of the techniques may be found:

a. * Strategic Options Development and Analysis (SODA) (Eden, 1994).

b. * Soft Systems Metholdology (SSM) (Checkland and Scholes, 1999).

c. * Strategic Choice, including the Analysis of Interconnected Decision Areas (AIDA).

d. * Robustness Analysis.

e. * Metagame Analysis.

f. * Hypergame Analysis.

g. Analytical Hierarchy Process (Saaty, 1980).

h. Decision Analysis (Watson and Buede, 1988).

i. Decision Conferencing (Phillips, 1989).

j. Dialectic Inquiring Systems (Churchman, 1971).

k. Idealised Planning (Ackoff, 1974; 1979).

l. LAMSADE School (Moscarola, 1984).

m. Strategic Assumption Surfacing and Testing (Mason and Mitroff, 1981).

Any of techniques and approaches that may be employed within IISD.

6.19 Group Model Building Project Methodolology

Further to the work of Vennix (1996) on group model building, and Coyle (1996) on system dynamics, the following general procedure for conducting a group model building project is suggested. See Figure 6-5, below.

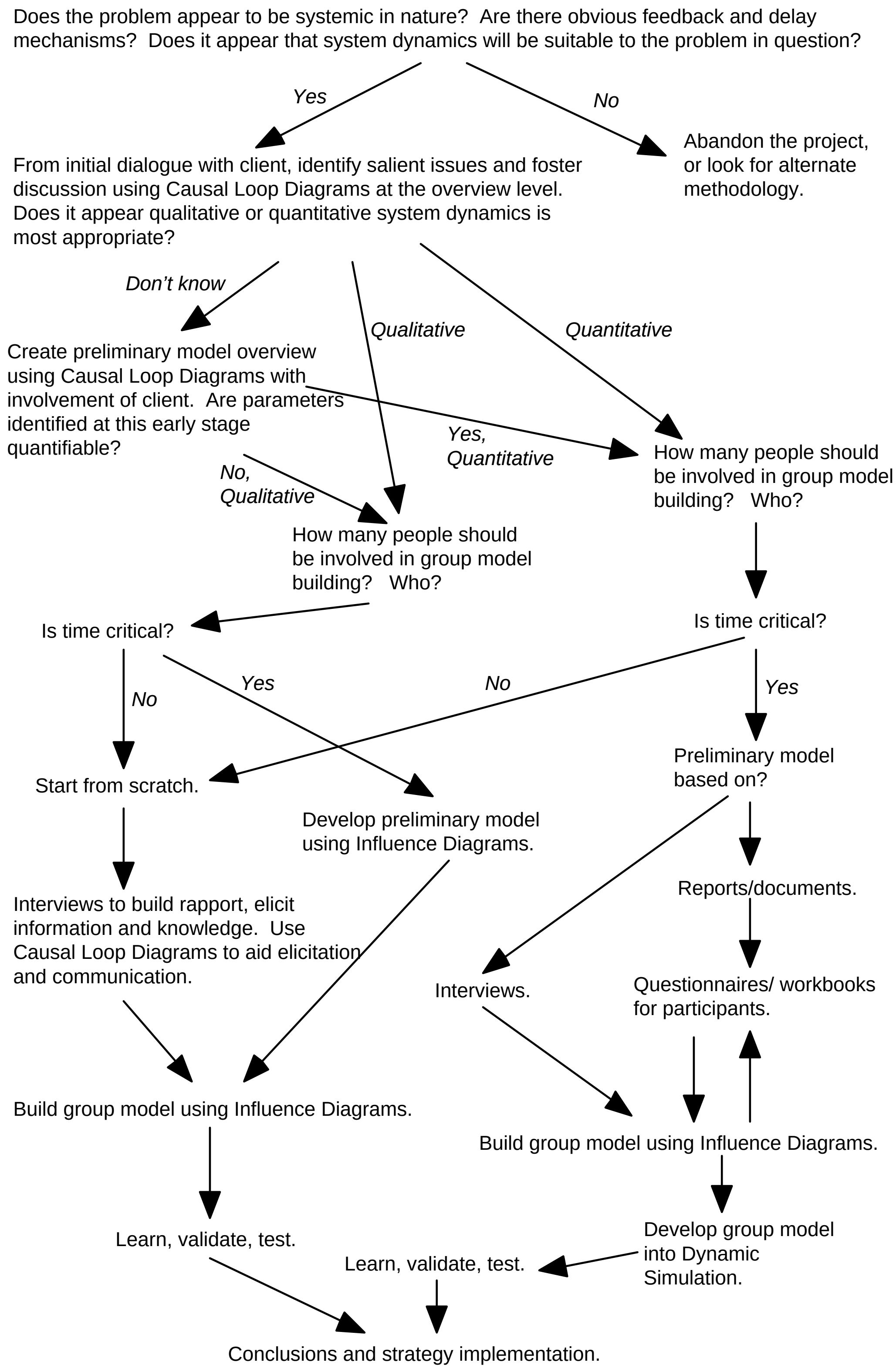


Figure 6-5. Group Model Building Project Methodology (1)(2)(3)(4)

<u>Notes:</u>

1. Developed by McLucas, 20 May 97, after Coyle, 1996: 18-47 and Vennix, 1996: 101-139.

2. This methodology suggests incorporation of Coyle's influence diagramming approach because of the rigour it brings. This approach permits the option of developing strategies using qualitative techniques, more rigorous and robust than 'conceptual' causal loop diagrams, potentially without the need to resort to quantitative analysis.

3. Concept mapping has since been found to be more useful, than causal loop diagrams, in the early stages of finding out about a problem situation. Equally, SSM could be used.

4. Its use is suggested within the framework of Iterative and Integrated Strategy Development (McLucas, 1998).

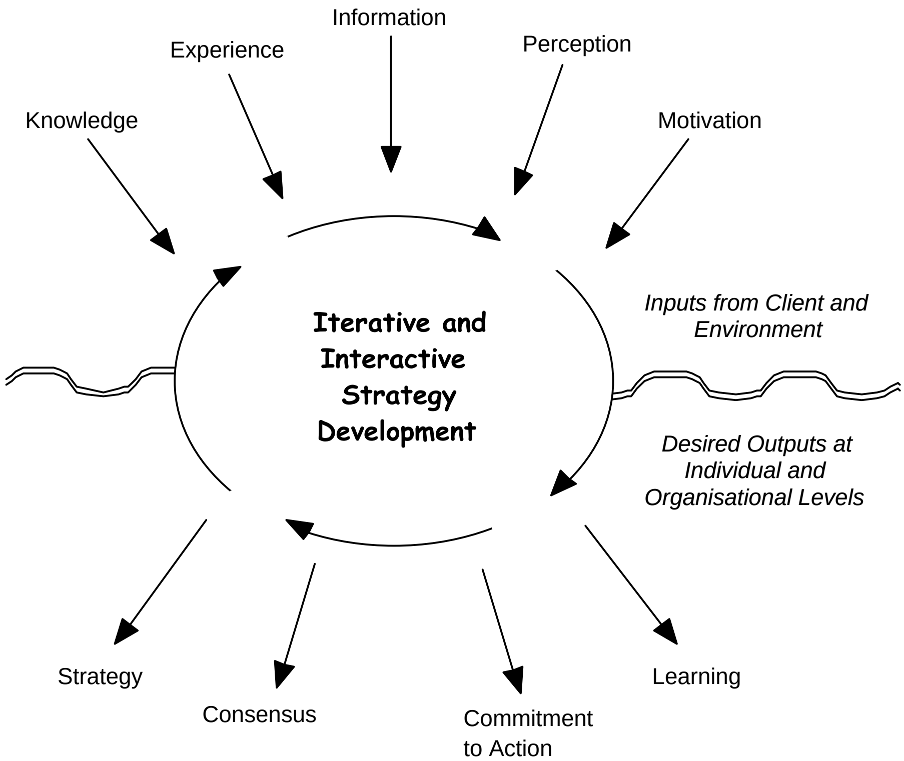


Figure 6-6. Iterative and Interactive Strategy Development (1)(2)

<u>Note:</u>

1. Circular arrows denote an iterative process through which concepts, causal relationships, feedback and delays are analysed. This may be envisaged as a spiralling process where radial distance from the *time* axis (vertically out of page) increases or decreases with *successive alternating cycles of divergence and convergence*: knowledge elicitation and data gathering (divergence activities), analysis, problem definition, conceptualisation, model development, simulation, and policy analysis (convergence activities).

2. IISD is action research. See 1.6 and Figure 1-1.

3. Iteration is often used in engineering highly complex systems. Iteration is frequently depicted as a 'waterfall' with information feedback to inform experiential learning, or action leading to revision of specifications and

design (Sage: 1995; Stevens, et.al., 1998: 194).

6.20 IISD - Inputs and Outputs

The key inputs to IISD from the client and the environment, that is, from the problem space are: knowledge; experience; information; perception; and motivation. The key outputs into the solution space, from IISD to the individual and organisation are: learning; consensus; commitment to action; and strategy.

6.21 Knowledge

Knowledge of the factors affecting the problem and their interrelationships is held primarily by those faced with the problem at the outset; the key stakeholders, managers and decision-makers. An important task of the analysts is to elicit that knowledge. The relationships between managerial cognition, operative knowledge, knowledge elicitation and problem definition are examined at 2.3, Figure 2-3, 2.4 and generally at Chapter 2.

6.22 Experience

Experience may be resident both in the decision-maker's and analyst's teams. It may also be necessary to solicit help from those specialist, or knowledgable, in a relevant area. Hypotheses developed during problem conceptualisation, see 2.1, strategy formulation and analysis should be subjected to testing against experience, in order to facilitate continued validation and revision of mental models, and to enable experiential learning, see 1.10, 1.13, 2.5 - 2.11. Developing mental agility through scenario planning, see 2.22 and 2.23, may help in developing experience more rapidly than might occur otherwise, thereby producing more effective learning, see 6.22.

6.23 Information

Throughout, the requirements for information will need to be reviewed as the focus on various parts of the problem changes. Sufficiently accurate and timely information is critical to both development of strategy and to learning. The information needed must be identified and obtained. Seeking out, and obtaining, the necessary information can be hampered by deliberately placed or naturally occurring barriers. See 2.25.

6.24 Perception

Perception is inextricably linked to our mental models and, similarly, is shaped by physical and emotional experiences throughout our lives. It is tied to deeply ingrained assumptions, values, generalisations, and mental images, which in combination influence how we view the world. Perception can be both an aid and a significant barrier to understanding and model building. Whilst soft operations research techniques may facilitate recording alternate perceptions of the same problem, system dynamics modelling can present only one perception of the problem at any time. Perceptions are not static. Ackermann, Eden, and Williams (1997) observed that perceptions changed as their study proceeded, thereby reinforcing the requirement for an iterative approach.

Vennix observes:

> … research has convincingly shown that differences of viewpoint [perception] can be very productive. They may help to challenge the implicit assumptions about situations and thus help prevent a premature problem definition. The more different perspectives taken into account, the smaller the chances of premature problem definition and 'solving the wrong problem'." (Vennix, 1996: 1).

A suitable problem-solving methodology should recognise and exploit differences in perception. Checkland, in SSM, recognises this and expresses it through the notion of *weltanschauung*, the need to accommodate varying perspectives. The elements of SSM are described at 2.28 and Figure 2-9, have been identified to emphasise the importance both of perception, and of a holistic view, in the process of finding out about a problem situation.

6.25 Motivation

Having a strong desire to solve a problem or, alternatively, to resist change are manifestations of motivation. Stakeholder motivation needs to be gauged then carefully monitored. It is important to remain cognisant of political influence as a motivating factor. As various strategies are offered, reviewed and evaluated, their political acceptability will be a matter for debate. Ultimately, the chosen strategy will have to be fully supported by the client organisation and, especially, its senior executives. The likelihood of acceptance will be considerably higher if decision-makers have been involved through every step of the process. The process, cognitive maps and models must be accessible and understandable to the decision-maker in order to encourage his involvement and foster positive motivation. Remediation of 'wicked' problems involves change. Frequently this is organisational change. Organisational change demands strong leadership and the generation of considerable effort to maintain high levels of motivation to see the change through to completion.

6.26 Learning

Learning about the problem will alter stakeholder's views and may well change the nature of the problem. To foster individual and organisational learning, models need to be developed with intimate involvement of, and interaction with, the decision-makers. Testing and validation of models must be undertaken progressively throughout. See Chapter 2.

Argyris (1994) coined the term 'double-loop' learning. See 1.3. Adult learning is double-loop learning through which greater insight and understanding results; we continually develop and test hypotheses of real world behaviour and retain this learning as our personal mental models. An overview is shown at Figure 6-7.

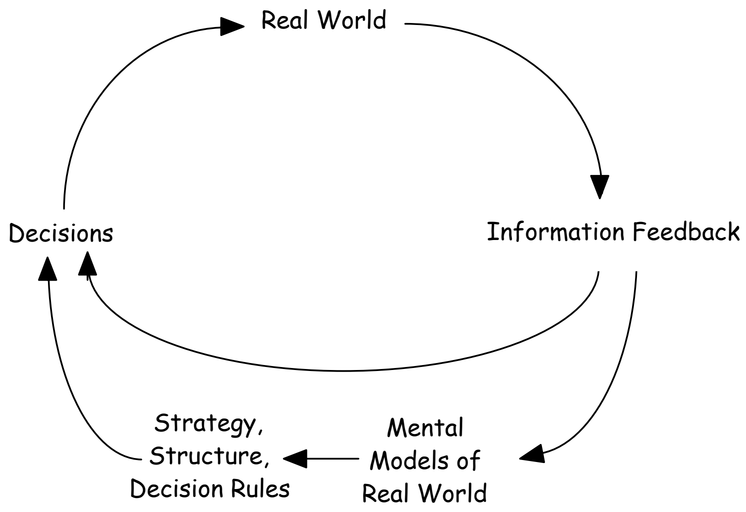


Figure 6-7. Feedback from Real World can Cause Changes in Mental Models (1)(2)

<u>Notes:</u>

1. Sterman (1994: 296)
2. Sterman (2000: 19) includes the additional feedback link from 'Mental Models of Real World' to 'Information Feedback'.

> In system dynamics, the term *mental model* stresses the implicit causal maps of a system we hold, our beliefs about the network of causes and effects that describe how a system operates, the boundary of the model (the exogenous variables) and the time horizon we consider most relevant - our framing or articulation of a problem (Sterman, 1994: 294).

Feedback from the real world provides a basis upon which we revise our mental models and, in turn, devise future strategies and personal decision rules.

Sterman explains:

> For learning to occur, each link in the two feedback loops must work effectively, and we must be able to cycle around the loops quickly relative to the rate at which changes in the real world render existing knowledge obsolete. Yet, in the real world... these feedbacks often do not operate well." (Sterman, 1994: 296).

Sterman also explains that various impediments slow or prevent these learning feedbacks from functioning, allowing erroneous and harmful behaviours and beliefs to persist. The barriers to learning include the dynamic complexity of the systems themselves; inadequate and ambiguous feedback; inability to simulate mentally the dynamics of our cognitive maps; poor interpersonal and organisational inquiry skills; and poor scientific reasoning skills. To be successful, methods to enhance learning about complex systems must address all these impediments (Sterman, 1994: 291-2). Sterman suggests an idealised set learning loops, which involve testing and validation of mental models and the development of these into more formal models capable of withstanding detailed scrutiny. The aim is to develop and test ideas in a *virtual world* before *real world* application. This idealised learning process, shown diagrammatically at Figure 6-8, is fundamental to IISD.

Before attempting to develop alternative strategies or evaluate them in the virtual world, IISD captures the mental models of decision makers, experienced personnel, stakeholders and gatekeepers as appropriate. These mental models must be in a form understandable and transparent to all, and amenable to analysis. IISD sets out to enhance learning and exploit individual mental models, meld them in to a perspective accepted, agreed, and owned by the decision makers. This becomes shared understanding or a shared reality. An important aim of IISD is to develop shared reality into a group model for further analysis in the system dynamics modelling virtual world before evaluation of alternate strategies in preparation for real world implementation.

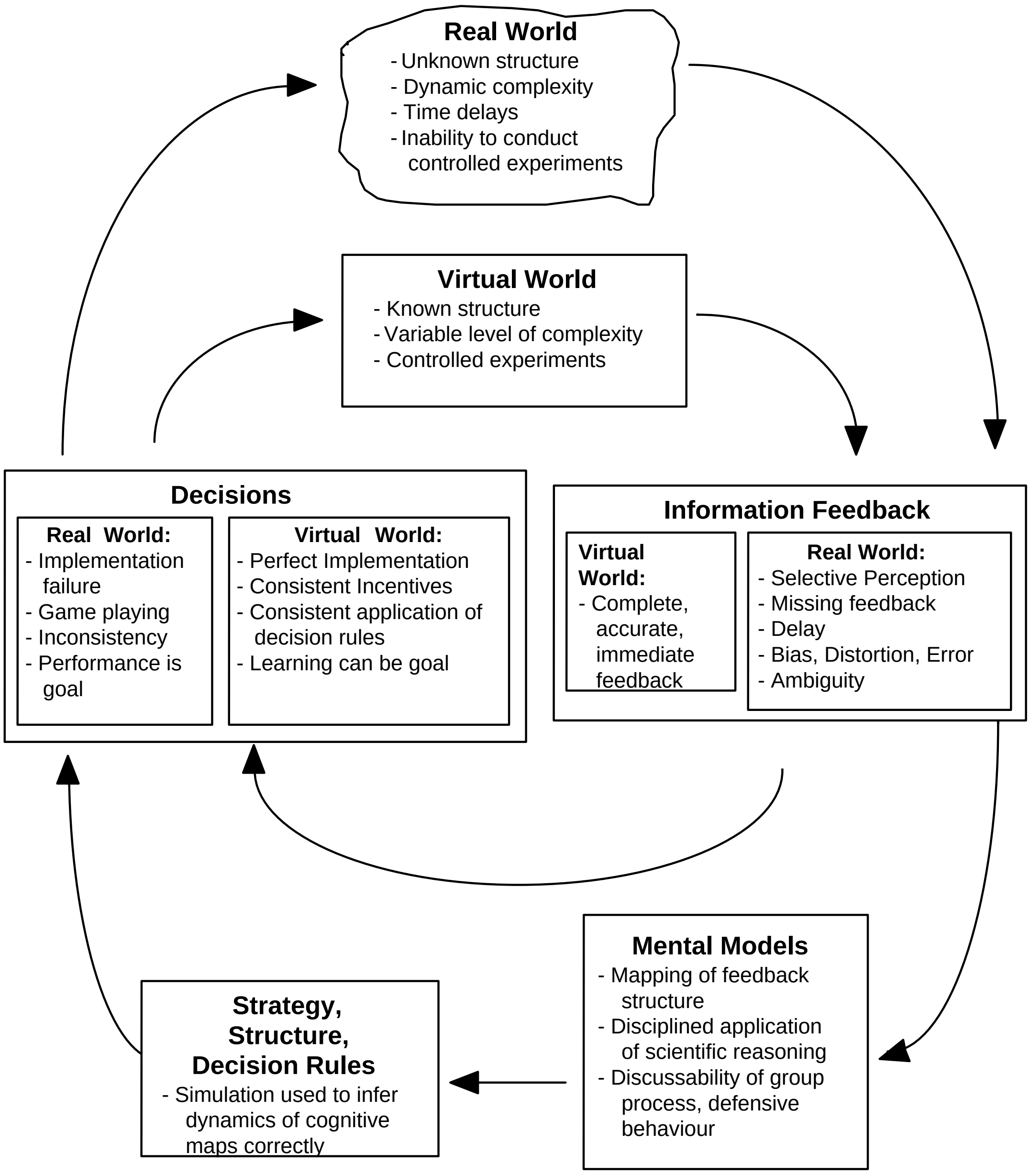


Figure 6-8. Idealised Learning Loops (1)

Note:

1. Sterman (1994: 318).

Espejo (1994) explains the nature of shared reality in organisations:

> Organisations are the product of ongoing processes in which people negotiate with each other - not necessarily with the same negotiating power - their organisational constructs and thereby constitute their organisations. Indeed, participants generate distinctions of their own, which they use to coordinate their actions, and through recurrent coordination of actions (ie. language) they create a consensual domain of action, or shared reality... This reality is grounded in cultural processes based on

> language. The risk is to forget that a shared reality depends on this generative process... Forgetting this simple point may be a source of many conflicts and naive assumptions...” (Espejo, 1994: 204).

Specifically, IISD builds on Sterman’s idealised learning loops to reduce barriers to learning by:

a. encouraging continual and intimate involvement of the decision making team;

b. eliciting knowledge, defining problems, and conceptualising systems using soft operations research techniques;

c. articulating and re-framing perception through individual interviews and group workshops;

d. developing and communicating ideas using influence diagrams of the feedback structure of the problem;

e. developing, as appropriate, system dynamics models and undertaking interactive simulations which permit the client to experiment with alternate strategies; and

f. methods to improve scientific reasoning skills, strengthen group processes, and overcome defensive routines for individuals and teams.

6.27 Consensus and Commitment to Act

Consensus cannot be mandated nor is it an automatic by-product of problem analysis. It can only be achieved through concerted and well-directed effort from the earliest stages. Soft operations research methods have greatest applicability to problem definition and conceptualisation. Close cooperation between decision-maker and analyst through these stages builds understanding and, therefore, is more likely to lead to consensus. Other benefits are: down-stream acceptance of more traditional techniques such as modelling and simulation; and commitment to action:

> It is our belief [Eden and Simpson], and it seems to be the belief of our clients, that it is a focus on the ‘softer’ issues at the beginning... which later enables participants to use more traditional analysis in an effective manner (Rosenhead, 1989: 70).

> …the primary goal is not to build *the* model of *the* system, but rather to get a team engaged in building a system dynamics model of a problem in order to see to what extent this process might be helpful to increase problem understanding and to devise

> courses of action to which team members will feel committed... team members exchange their perceptions of a problem and explore such questions as: what exactly is the problem we face? How did the problematic situation originate? What might be the underlying causes? How can the problem be effectively tackled? ... ‘fact’ is separated from ‘value’. The primary focus is descriptive and diagnostic: the way the team members think a system works is separated from the question how they would like a system to work.” (Vennix, 1996: 3).

Because when properly applied, soft operations research techniques require closer cooperation between analysts and decision makers, they have reputed strength in enhancing consensus and commitment to action (Pidd, 1996). Among the most important stakeholders in strategic issues are the decision-makers themselves. IISD sets out to involve them as far as their busy schedules permit. Further, IISD recognises the need to accommodate managers preferences for:

a. face-to-face dealing;

b. verbal communications and briefings rather than written reports; and

c. graphical presentation of information (concepts, influence diagrams and models), and dynamic demonstration of strategic alternatives.

Decision-makers often prefer one information type and processing option (Churchman, 1971; Mason and Mitroff, 1973; Nutt, 1989: 113). See Table 6-2, below.

These preferences lead to four choice-making styles, the descriptions of which have been extracted from Nutt (1989: 112-116) and reproduced below. Further to the discussion of choice and decision-making at Chapter 2, inclusion of descriptions of these styles is intended to emphasise that highly prescriptive elicitation, conceptualisation and modelling processes applied in ignorance or neglect of them can result in failure. Having to deal with decision-makers who employ different styles can have a significant effect on the way conceptualisation and modelling are approached.

Preferred Mode of Processing		**Preferred Mode of Gathering Information** Sensation (**S**)	**Preferred Mode of Gathering Information** Intuition (**N**)
	Thinking (**T**)	*Systematic* (**ST**) **Information:** quantitative measures **Warrant:** statistical significance or axiomatic logic **Decision Aids:** cost–benefit analysis and evaluation research	*Speculative* (**NT**) **Information:** future possibilities **Warrant:** assumptional flux and stochastic parameters **Decision Aids:** decision trees with sensitivity analysis
	Feeling (**F**)	*Judicial* (**SF**) **Information:** current situation or circumstances **Warrant:** acceptance and compromise by interested parties **Decision Aids:** decision groups	*Heuristic* (**ST**) **Information:** current possibilities **Warrant:** experience and judgement **Decision Aids:** mutual adjustment

Table 6-2. Choice Styles

The four 'model' choice-making styles are:

a. *Systematic - Sensation Thinking* (ST) *Style.* Managers using an ST or "systematic style" consciously structure their decisions by developing ways to look for cues in evaluating data. The tactics they use to search may vary from one systematic decision-maker to another, but each stresses hard data and logical analysis, and each attempts to devise rules that will govern the decision process. Variations and adaptations occur as "tactics", which are then applied to new and different tasks. The preference for careful analysis with hard data suggests that systematics would prefer to use analytical decision aids such as mathematical models or statistical techniques. Warrants such as statistical significance and mathematical logic are used to validate the need for action. Systematic decision-makers prefer to compare options by using quantitative criteria and to base their decisions on the findings of the analysis. ST managers become uneasy with decisions that are not amenable to this type of treatment. Some type of cost-benefit or cost-effectiveness analysis is thought to be necessary to consistently make “good” decisions. Unwarranted theorising and moralising are believed to result when qualitative information or personalities clutter up a decision. Managers with these views see people with different styles as misusing quantitative information. These views are often expressed by the statement that most things are measured with a micrometer, marked with chalk, and cut with a meat axe. The systematic decision-maker feels no compelling urge to consider context and frequently ignores the way shifts in the environment, such as changes in oil prices, could influence the merits of alternatives.

b. *Speculative - Intuition Thinking* (NT) *Style.* The “speculative” or NT decision-maker tries to subject hypothetical possibilities to logical analysis. Like systematic decision-makers, speculative individuals follow logical steps in the analysis, but are more concerned about contextual factors, using analysis to devise and test several premises. Information that describes the influence of crucial contingencies, such as demand or use estimates, illustrates key premises that speculative decision-makers often consider. Decision aids congruent with this style are decision trees and sensitivity analysis. The NT regards future possibilities, expressed as data-assumption linkages, as key facts suggesting a warrant of assumptional flux. To isolate a preferred course of action, NTs relax assumptions about key factors to see if a pessimistic as compared to an optimistic view of these factors would call for different choices. Speculative decision-makers want to use a structure to organise their decisions and regard those without a structure as fuzzy thinkers. They are intrigued by unknown-unknowns and how they know they know. Speculatives are leery of decision-makers who espouse the use of intuition derived from experience to make decisions, wondering whether good judgement comes from experience or experience comes from bad judgement. According to this view, once something happens, no mater how accidental, it tends to be regarded as a manifestation of a hidden reality.

c. *Judicial - Sensation Feeling* (SF) *Style.* A “judicial” or SF decision-maker prefers to rely on consensus to select a course of action. Such individuals disregard general issues to focus on human relations that appear to influence choice, using facts and details to describe these relationships. Decisions are treated as unique and each is considered on its merits. Reality is what a key body, such as an organisation's board of directors, can agree about. The judicial decision-maker seeks quantitative information but processes the information by seeking an agreement about the information's meaning. Advocating interaction to sort and reconcile evaluation data is consistent with the preferences of a judicial manager. People's perceptions of the current situation are facts to a judicial, and what people will accept is the *key* warrant used to endorse action. Action taking becomes feasible for an SF when negotiation has identified an acceptable course of action. Judicial managers prefer to consider information from a variety of sources, using decision aids such as group process, to do so. Judicials try to avoid the "straight jacket" they believe is imposed by formal models. Only interpersonal contact can cater to judicial decision-makers' preference for hard data and their need to understand the views of their peers when making choices. The "community of minds" sorts through the information that is uncovered to isolate a course of action. Cost-benefit and cost-effectiveness criteria are considered, but the importance of such information hinges on its presentation and its source. The result is synthesis of cost-effectiveness and cost-benefit data, based on the synergistic insights of the group, which is believed to produce good decisions.

d. *Heuristic - Intuition Feeling* (NF) *Style.* Managers with a heuristic or NF style rely on unverbalised hunches or cues and prefer to defend their choice by its "fit" to their experiences. Social responsibility and quality of life often form the basis for a choice. Analytical approaches are viewed as unable to capture the complexity in most important decisions. The heuristic decision-maker believes that values are a crucial aspect of most decisions and that choices cannot be made without considering the decision's value context. To make a decision, the heuristic decision-maker attempts to balance conflicting claims. Politics and bargaining through mutual adjustment, are preferred approaches. Heuristics believe that important decisions can seldom be uncoupled from the personal views and desires of powerful stakeholders who

> are influenced by the decision. Facts become the NF's perception of these views and desires, backed by a warrant that stresses the NF's judgement and experience. Reconciling the values and beliefs of key stakeholders is a precursor to action. Heuristic decision-makers see decision making as a practical exercise that must cater to the whims of key people and the culture of the organisation they represent. A point between conflicting claims and counterclaims that balances opposing views is sought and the political and moral consequences of each alternative course of action are stressed. Heuristic decision-makers view analytical approaches as inappropriate because they ignore or fail to capture the political and moral concerns posed by alternatives. They resonate to George Bernard Shaw's observation that all the economists in the world laid end to end would not reach a conclusion. Group decisions are avoided because a group may force the decision-maker to disclose information before the consequences of disclosure can be assessed. Decision groups are seen as producing "pooled ignorance", which in the mind of the heuristic decision-maker seldom leads to wisdom.

6.28 Strategy

Successful implementation of an appropriate strategy depends on the inputs listed above in an environment of close and continuous decision-maker involvement, where learning is fostered and models are jointly and progressively developed. The importance of continuous decision-maker involvement is often overlooked. This can lead to non-acceptance of lessons learned from modelling:

> To prevent policy improvement from becoming an academic exercise, the modeler must be concerned from the beginning about eventual implementation. Conclusions from formal models often fail to be implemented (Roberts, 1980).

Modelling 'fails' when courses of action or alternatives offered by, or derived from, modelling do not result in implementation of a strategy, policy or decision by management. Failure is not likely to occur because system dynamics is an inappropriate tool for the task. Ironically, the likelihood of failure increases when modelling and simulation efforts lack support or detailed understanding by those for whom they were designed or, indeed, by management who sponsored model development in the first place. An example of failure to engage senior decision-makers sufficiently in the modelling effort, is at Chapter 10. A high level of client involvement is critical to ultimate strategy implementation.

6.29 Other Methods of Capturing and Analysing Mental Models

Capturing and analysing mental models is fundamental to IISD. There are several tools available for this task, including Rosenhead (1989):

a. Strategic Options Development and Analysis - Eden and Simpson.

b. Soft Systems Methodology - Checkland.

c. Strategic Choice - Friend and Hickling.

d. Hypergame Modelling - Bennett, Cropper and Huxham.

6.30 Threats to IISD

Threat to IISD, include lack of acceptance by stakeholders and gatekeepers resulting from suspicion, fear or mistrust. Barriers to learning and effective decision-making at 2.5 are also serious threats. Threats to successful application of IISD can be real. Argyris (1994) warns of basic but strong values, apparently universal amongst decision-makers, the purpose of which is to avoid embarrassment or threat, feeling vulnerable or incompetent. The resultant defensive reasoning encourages individuals to keep private the premises, inferences, and conclusions that shape their behaviour and to avoid testing them in a truly independent, objective fashion. See 2.3 and Figure 2-3. Further, the observation that somebody in the client organisation is reasoning defensively is yet more defensive reasoning (Argyris, 1994: 90). Overcoming barriers such as defensive reasoning and insidious aspects of group dynamics, requires awareness and high levels of facilitative skill.

6.31 Summary – Chapter 6

This chapter describes a framework for addressing complex, dynamic, systemic problems. Other than the use of quantitative system dynamics techniques, the quantitative methods which might be incorporated into IISD are not prescribed. Whilst a number are offered, many others could be used. In Chapter 7, how IISD is used is explained by way of a tutorial. Case studies at Chapters 8, 9, and 10 describe cases to which IISD was applied.

6.32 Significant Contributions Made in Chapter 6

Rather than working from an assumed list of principles of method, an initial set of principles were developed from empirical analysis, Chapters 3 and 4, combined with observations from a review of the systems thinking and system dynamics literature. This set of principles at 6.4 is unique. It will be tested through case applications in the following chapters. This will lead to their further development. The principles take into account practical issues and recognise, contrary to much of the system dynamics literature, that at the outset (usually) little is known about the problems at hand. The creation of a new framework for addressing complex, dynamic, systemic problems is not significant by itself because other researchers have produced similar things. However, where and how qualitative and quantitative methods fit into IISD and the general framework of systems thinking and system dynamics modelling is significant because it identifies the intended products of each stage or activity. See Figure 6-6. This is essential to consideration of how integration of qualitative and quantitative methods might be achieved, and how useful such integration might be in facilitating strategic decision-making.

CHAPTER 7: APPLICATION OF IISD - ADDRESSING COMPLEXITY AND SYSTEMIC BEHAVIOUR IN ENGINEERING MANAGEMENT: A TUTORIAL FOR REAL-LIFE PROBLEMS

Synopsis

In 2.11, 2.18 and 2.21 it was argued that the human mind is ill-adapted to conceptualising and mentally simulating complex problems where delayed feedback exists. It was also argued that when we set about solving complex problems we must take into account the different perspectives of the various stakeholders. Working through such problems following the principles of action research, involving stakeholders as far as possible were advocated in 1.6, 2.2 and 6.3 – 6.6. This chapter outlines how Iterative and Interactive Strategy Development (IISD) and system dynamics modelling, as described at 6.11, are used to compensate for human cognitive shortcomings. A management problem is presented and analysed through the medium of a tutorial. On the surface, this problem appears easy to solve. In practice, it has proven otherwise. Logical and well-intentioned management interventions attempted to date have proven ineffective. Some resulted in counter-intuitive changes.

The principles of method, described at 6.4, are demonstrated in the context of the tutorial. The tutorial takes us through problem conceptualisation, identification of options, strategy development, and evaluation of effectiveness of selected strategies. A set of pitfalls and pointers is compiled. This is a summary of observations of methods used, and results achieved, by UNSW Management Masters and undergraduate engineering students in their attempts to solve this problem.

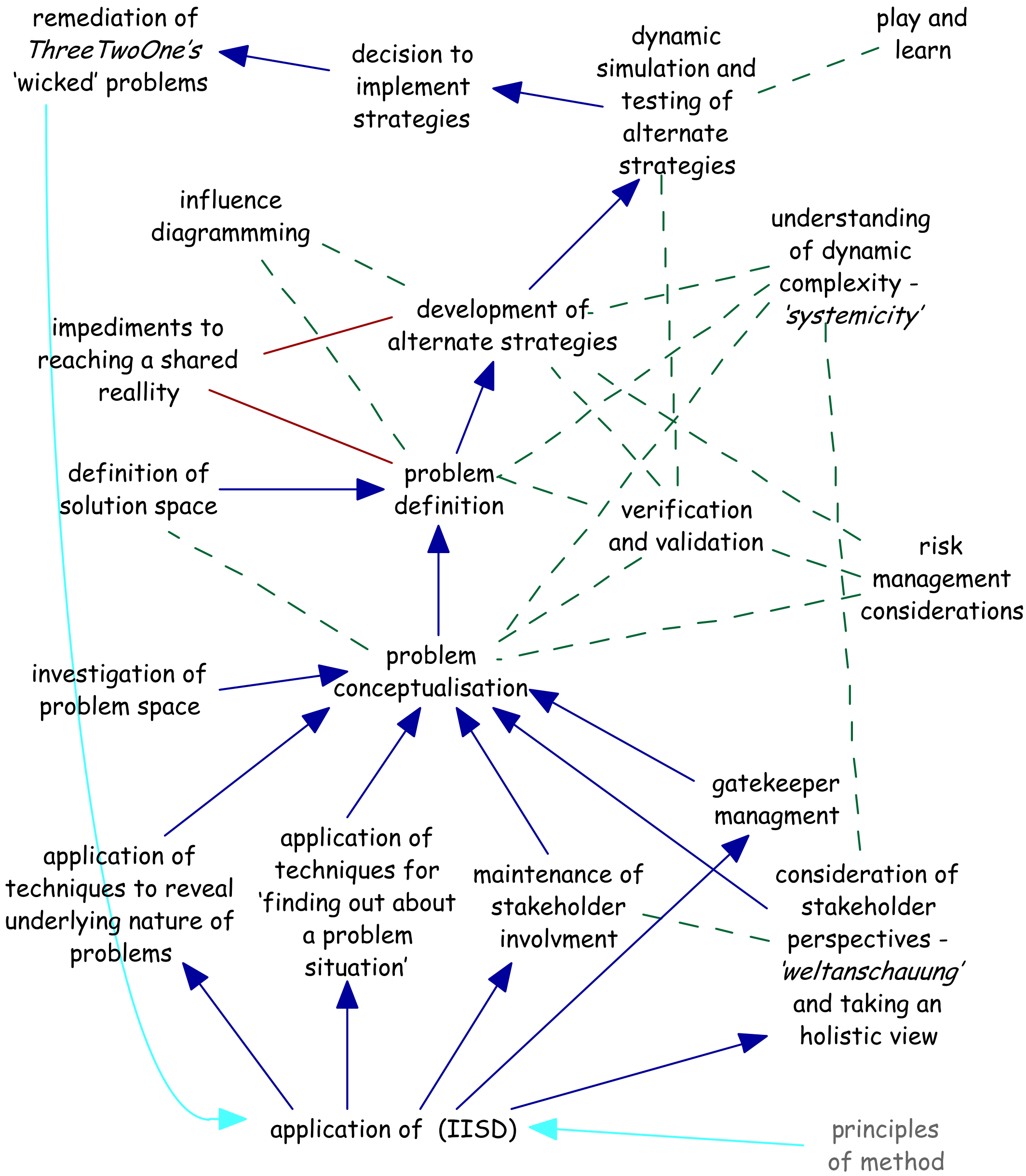


Figure 7-1. Concept Map - Chapter 7 (1)

<u>Notes:</u>

1. Concepts shown in black text are contained in this chapter.

An implicit and fundamental assumption behind the selection of business performance indicators is that decision-makers can use them effectively to make appropriate adjustments to the way business is conducted. This presumes decision-makers can judge, with reasonable accuracy, the consequences of their decisions, both in the short and long terms.

However, there is abundant research in the fields of system dynamics, cognitive behaviour, and decision-making, which suggests that managers are ineffective in managing dynamically complex tasks. Mosekilde, Larsen and Sterman (1990) present the results of 48 simulations of the 'Beer Game' (a simulation of a simple factory-warehouse-retail system) run with 192 MBA students and senior business executives. The decisions taken by players, in this environment of delays and systemic feedback resulted in operating costs the basis upon which player performance is gauged, 10 times higher than the best achieved.

Simulations at the Australian Defence Force Academy show a similar pattern. In both the MIT and ADFA simulations, managers and graduate students failed to comprehend the contributions made by feedback, especially delayed feedback, in creating dynamic behaviour of systems. In more recent experiments, where graduate students had full information, training, incentives and opportunities for gaining experience, Diehl and Sterman (1995) still found poor managerial performance in situations where feedback strength and delay changed over time. They found the subjects were often outperformed by a simple 'no-control' rule. That is, totally random business decisions gave better results than the considered judgement of their MBA students. Diehl and Sterman argue that the mental constructs and heuristics that managers bring to bear on complex tasks are fundamentally dynamically deficient:

> Subjects were unable to account well for delays and feedback effects because (1) people's mental representations of complex tasks are highly simplified, tending to exclude side effects, feedback processes, delays, and other elements of dynamic complexity; and (2) even when these elements are known, people's ability to infer correctly the behaviour of even simple feedback systems is poor (Diehl and Sterman, 1995: 2).

The implication of this work is that managers require specialised decision support tools to respond appropriately to performance indicators, which are affected by delayed feedback.

There is another fundamental issue here that of ensuring that the right problem is always addressed. This tutorial demonstrates how to systematically identify and define relevant issues affecting the problem, and map the interrelationships between those issues. The aim is to identify what contributes to business dynamics so that management effort can be directed to achieving greatest effect.

This tutorial demonstrates practical application of Iterative and Interactive Strategy Development (IISD) described in Chapter 6. The tutorial explains, step-by-step, how IISD is applied. The tutorial also shows effective ways of defining, or conceptualising, a problem and how to compensate for human cognitive shortcomings in dealing with business dynamics whilst making best use of human cognitive strengths.

The Civil Engineering School at the Australian Defence Force Academy runs undergraduate and postgraduate units in systems thinking and system dynamics modelling to give students the intellectual and analytical tools to compensate for human cognitive limitations when dealing with dynamic complexity. In a simplified form, the following case study forms the foundation of the undergraduate unit where emphasis is on building system dynamics modelling skills. Undergraduate students have limited opportunity to develop problem conceptualisation skills. By contrast, Masters students are given the full version of the problem and are tasked with solving it. They commence by playing the roles of various stakeholders. For them the main emphasis is on building problem conceptualisation skills and a concomitant appreciation of complexity of real-life problems.

7.1 Nature of the Tutorial Problem - Brief Overview

The tutorial focuses on an engineering management problem taken from real-life. *ThreeTwoOne-Ready Pty Ltd* owns a small urban concrete batching plant. Competition is stiff and *ThreeTwoOne* knows that client service is paramount. An inability to respond on time and on quality to customer demands will lose orders in the short-term, and clients in the longer term.

In response to phone orders placed by clients in the building industry, concrete is mixed from stocks of raw materials. Aggregate, sand and cement are mixed to order and delivered to construction sites in the local area. There are a number of other companies mixing and delivering concrete to construction sites. *ThreeTwoOne's* directors and employees are conscious that any inability to deliver, or failure to respond to customer demands, is most likely to lead both to lost orders and lost goodwill.

Consideration of the problem starts with the company owning three delivery trucks. The company often utilise private delivery trucks, for which a significant premium is paid through short-term contracts. The company directors have agreed that their immediate priority is to invest in two additional delivery trucks, making a total of five. This decision appears inevitable because of the cost of employing owner-drivers on an *ad hoc* basis.

After a period of time it becomes clear that even with five company-owned trucks, customer demands cannot be met with any certainty. The company continues to struggle to meet its goal to build a reputation as a reliable and responsive supplier. Directors of *ThreeTwoOne* are growing increasingly anxious about the company's ability to remain competitive in the longer-term.

7.2 The Directors' Quandary

At a company meeting some 12 months ago the directors advised salaried drivers, clerk, batch-plant operators, foreman, and plant supervisor that they were planning to invest in additional trucks. The directors expected this suggestion to be warmly received by employees. Instead, they were met with a barrage of complaints about antiquated concrete mixing machinery in the batch-plant, having to work unpredictably long hours, continual avoidance of employee suggestions about ways to improve productivity, and discontent that employees were being blamed for loss of customers. Clearly employees were unhappy and this, the directors' latest initiative, did not receive the vital support for which they had hoped.

At this stage the Directors were committed to investing in two additional delivery trucks and were equally committed to determining how many trucks were needed to best service customers: once the optimum number of trucks had been procured and were operational, surely employees would be much happier? Despite procurement of additional trucks, and these being driven by salaried employees, again the directors find themselves faced with investing in additional trucks to meet customer expectations for responsiveness. However, business continues to be lost through the inability, from time-to-time, of *ThreeTwoOne* to deliver in accordance with customers' unpredictable demands.

Faced with their quandary, the directors sought advice from engineering management consultants. In response to consultants' advice the company began collecting data about key aspects of their business such as customers' ordering patterns, responsiveness in dispatching orders, and delivery turn-around times. Directors hoped this information would assist in future business strategy development. Preliminary analysis suggests there are no problems with availability of raw materials.

It is intuitively obvious that more trucks are required, but now the directors are becoming concerned that even if trucks are procured employees may continue to be dissatisfied, customers will continue to take their business elsewhere and *ThreeTwoOne* will remain marginally competitive at best. The directors are worried about the company's competitiveness, where best to invest, and what to do next.

The problem remains despite the experience, intuition and judgement of the directors. Contrary to promising short-term improvements of the past year, long-term improvements remain elusive. Students are tasked, as engineering management consultants, to devise strategies to solve the directors' quandry.

7.3 Tutorial - Preview

The tutorial shows, through application of IISD (McLucas, 1998):

a. that the problem situation has to be clearly established before problem conceptualisation, that is problem definition, can commence;

b. how to reveal the true nature of the problem;

c. why remedial efforts attempted so far have not been effective;

d. how diverse views of stakeholders impact upon:

   (1) problem conceptualisation;

   (2) development of strategies; and

   (3) the process of selecting strategies to be implemented;

e. how to correctly define the problem space;

f. how the solution space is defined, based on consideration of:

  (1) risks; and

  (2) diverse stakeholder perspectives; and

g. how to use system dynamics modelling and simulation to:

  (1) aid understanding of dynamic complexity; and

  (2) analyse alternate strategy options.

The problem conceptualisation techniques demonstrated are not the only ones that may be used. Various problem conceptualisation techniques are listed at 6.29. The most important criterion is that they are *systems thinking* techniques, ones designed to accommodate the fundamental nature of systemic problems. Checkland (1993: 318) describes this type of thinking as an epistemology which, when applied to human activity is based on the four basic ideas: *emergence*, *hierarchy*, *communication* and *control* as characteristics of systems. When applied to natural or designed systems the crucial characteristic is the *emergent properties* of the whole.

Supporting techniques such as Delphi Method (Dalkey, 1969; Brown, Cochran, Dalkey, 1969a; Brown, Cochran, Dalkey, 1969b; Brown, Cochran, Dalkey, 1970; Linstone, and Turoff, 1975) may be needed to aid parametric estimation, or aid in hierarchical analysis, viz, Saaty Method (Saaty, 1980).

Regardless of the means used for conceptualisation, detailed analysis demands tools effective in dealing with dynamic, complex and systemic problems. System dynamics modelling has proven most valuable for this purpose. System dynamics modelling and simulation are used in an action research / action learning context for:

a. analysis of changes over time, and

b. enhancing learning about systemic and dynamic behaviour.

The main outputs of IISD are strategies built with the intimate involvement of stakeholders. Optional strategies developed are demonstrated and ‘flown’ on a purpose-built flight simulator. In the latter stages of IISD, stakeholders are encouraged to fly the simulator, freely changing the parametric values as often and in whatever combination, they choose. In this way, they are able to assess the suitability of the strategies and test them in a virtual world; a benign environment where pre-implementation rehearsal can be conducted without causing collateral damage. This also presents an opportunity for re-thinking the strategies before taking the critical step to implement them.

Correctly applied, system dynamics modelling is a powerful tool for addressing many similar problems. Limitations in the application of system dynamics are discussed separately at Chapter 5 and 13.

7.4 Putting *ThreeTwoOne-Ready* Back on Track – First Steps

Over several months, sufficient data has been gathered to permit detailed quantitative analysis, but this is set aside for the time being. The critical first step is to investigate the nature of the problems *ThreeTwoOne* faces by eliciting knowledge about those problems from key stakeholders mentioned at 7.2, above.

Stakeholders are gathered together so that operative or domain knowledge, see 2.3 and Figure 2-3, can be elicited as a pre-cursor to systematic problem conceptualisation. A series of workshops attended by subgroups of stakeholders with similar interests are recommended. Individual interviews work well, particularly when disparate views of the problem are expected, or conflict is likely, but interviews are most time consuming. This is discussed further at Chapter 10.

It is important to identify *gatekeepers* who need to be consulted, or interviewed, before workshops begin. Gatekeepers often control access to parts of an organisation or people within it. See 2.2. Note that in this dissertation, gatekeeper is taken to mean more than Andersen and Richardson (1997: 109) suggest. They use the term to describe a contact person within the target organisation. In this dissertation, a gatekeeper can be the same contact person but can be a person who overtly or covertly controls access to information, to people or can influence acceptance of management intervention processes. *Modelling gatekeeper* will be used in this dissertation as the term to identify the *gatekeeper* role defined by Andersen and Richardson.

Andersen and Richardson (1997) identify a number of activities to be undertaken in the process of planning knowledge elicitation, problem conceptualisation and group modelling workshops. They call these ‘scripts for group model building’. Their script headings, shown in Italics below, have been augmented by experiences from research work described elsewhere in this dissertation, to produce the following guide:

a. *Goal setting / managing the scope of work.* The modelling gatekeeper helps in setting the scope of work and identifying appropriate people with whom to work before the workshops are formally conducted.

(1) *Interviews with key managers.* These people help frame the first concept models used to initiate the group workshops. In *ThreeTwoOne's* case, the output of this initial meeting might be as shown at Figure 7-2, below. Equally it might be a sketchy concept map produced 'on the fly' during the entry interview.

(2) *Clarify audience and purpose.* The most important aspect is to ensure the right people are involved. Also, top-level management support for the effort can be critical. Support by top management must be demonstrated by their public sanctioning, and by their attendance at least for some of the time.

(3) *Clarify products.* It must be established from the outset what the expectations are in relation to the products deliverable at the end of each workshop, or modelling conference. The latter is the term used by Andersen and Richardson.

b. *Logistics:* Having the right room and logistic support is probably the second most important success factor.

(1) *Room layout.* Chairs should be comfortable, preferably swivelling to allow participants to turn easily to address each other or to combine into small sub-groups of three or four. Any medium that fosters dialogue and expression of ideas is valuable. To this end, Andersen and Richardson state a preference for large whiteboards or whole walls covered with erasable white static cling sheets for diagramming. Experience in the conduct of the research described in this dissertation has been that:

(a) Large whiteboards are most useful: the bigger the better.

(b) Large Post-it® Notes, or 'stickies', are useful for recording individual ideas, or concepts. They can be stuck on whiteboards or flip sheets in clusters or dispersed with additional information, such as arrows, drawn on the backing media. Eden and Ackermann (1998a) use similar resources, but prefer oval-shaped stickies, in conjunction with concept mapping in what they describe as the 'Oval Mapping Technique'.

(c) Electronic whiteboards, which incorporate the facility to produce photocopies of drawings, enable progressive recording of the flow of ideas. Screens of information can be copied and then detail on the whiteboard can be erased. This permits the group to continue pursuing ideas without loss of earlier thoughts.

(d) A projected computer screen can be highly valuable for focusing the attention of group members. However, used unwisely this same device can inhibit the flow of ideas.

(2) *Roles in the room.* Besides the participants there is a workshop, or group modelling, support team, which varies in size from two to five. The team members take on the following roles (Richardson and Andersen (1995: 113-137):

(a) *Facilitator / elicitor*. Functioning as group facilitator and knowledge elicitor, this person pays constant attention to group process, the roles of individuals in the group, and the business of drawing out knowledge and insights from the group. This role is the most visible of the five roles as the facilitator constantly works with the group to further the model-building effort.

(b) *Modeller / reflector*. This person focuses not at all on group processes but rather on the model that is being explicitly (and sometimes implicitly) formulated by the facilitator and the group. The modeller / reflector serves both the facilitator and the group. He thinks and sketches independently, reflects information back to the group, restructures formulations, exposes unstated assumptions that need to be explicit, and in general serves to crystallise important aspects of structure and behaviour. Richardson and Anderson stress that in their experiments, it was found necessary for both the facilitator and the modeller / reflector to be experienced system dynamics modellers.

(c) *Process coach*. This person focuses not at all on content but rather on the dynamics of individuals and subgroups within the group. Richardson and Anderson have found it both useful and annoying that their process coach is not a system dynamics modeller; such a person can observe unwanted effects of jargon in word and icon missed by people closer to the field. The process coach tends to serve the facilitator; his efforts being largely invisible to the client group.

(d) *Recorder*. Writing down or sketching the important parts of the group proceedings is the task of this person. Together with the notes of the modeller / reflector and the transparencies or the notes of the facilitator, the notes and drawings made by the recorder should allow a reconstruction of the thinking of the group. This person must be experienced enough as a modeller to know what to record and what to ignore.

(e) *Modelling gatekeeper.* This role is filled by a person within, or related to, the client group who carries internal responsibility for the project, usually initiates it, helps frame the problem, identifies appropriate participants, works with the modelling support team to structure the sessions, and participates as a member of the group. Aware of system dynamics literature and practice but not necessarily a modeller, the modelling gatekeeper is an advocate in two directions: within the client organisation she speaks for the modelling process, and within the modelling support team she speaks for the client group and the problem. The locus of the modelling gatekeeper in the client organisation will significantly influence the process and the results.

Whilst these roles are distinct and essential, more than one role may have to be filled by an individual when the size of the support team is constrained.

c. *Types of group task structure.* Like VanGundy (1992), Andersen and Richardson highlight the need to work through *divergent* followed by *convergent* activities. That is, an initial search for ideas and data followed by a narrowing of focus or distillation of the data. It is necessary to work through several cycles of divergent and convergent thinking. In Creative Problem Solving (CPS), VanGundy (1992: 17) suggests that as many as six cycles might be used, although this number is not always needed. The whole group moves rapidly and often from individual work to subgroup work to plenary-group work. Tasks can vary from divergent (brainstorming) tasks to ranking and evaluating tasks, to integrative or design-oriented tasks. Selecting sequence of elicitation exercises that yield fruitful, focused, and maturing group discussions is the challenge.

(1) *Divergent tasks.* Divergent thinking tasks (such as getting as many ideas as possible out on the table) are best supported by nominal group techniques. One group, or a number of small groups, generate lists of ideas or concepts. Andersen and Richardson then form a nominal group of the whole by moving from subgroup to subgroup and asking each person or subgroup to contribute only one idea (presumably their best remaining one) to the growing list of plenary group ideas. They then go around the plenary group as necessary to allow all the emergent ideas to be exploited. Like Anderson and Richardson, experience from this research effort is that such a nominal group approach:

(a) is more effective in divergent thinking tasks than inviting the entire group to be involved in a brainstorming workshop;

(b) avoids the tendency of a group to anchor its thinking on the first several ideas, concepts, or items put forward; and

(c) enables each sub-group to contribute and comment before any subgroup gets a chance to dominate.

(2) *Convergent tasks.* Once ideas have been elicited by the divergent

thinking task, such as brainstorming, and ranked in order of importance, convergent thinking commences. Products of the various iterations, earliest to latest, at the convergence stage, include:

(a) Choices regarding level of aggregation at which to work. This choice naturally follows a process of selecting which concepts to include or exclude. From that point it is a matter of working consistently at the same level.

(b) Identification of the six crucial CATWOE characteristics, which should be included in a well-formulated SSM, root definition, if SSM is being used. Use of SSM does not preclude the use of other systems thinking techniques at other stages in the process.

(c) A rich picture of the problem situation, if SSM is being used.

(d) Concept maps produced by each subgroup.

(e) Concept maps produced by the plenary group.

(f) Identification and specification of the boundaries to the problem space and solution space.

(g) Influence diagrams, following the conventions used by Coyle (1996: 18). Influence diagrams will become the basis for detailed analysis and critical review of forces and interactions. They hold the secrets about where the pressure points are, that is, where best to expend effort in seeking an answer, or developing a management policy. In some cases, more sophisticated quantitative models may not be required (Coyle, 2000).

(h) As an alternative to (g) above, a hybrid diagram of stocks and flows and causal loops (Levin et al., 1975: 27) may be produced.

Note: The role of causal loop diagramming in this process is discussed further at 7.5 below.

d. *Ranking and evaluation.* Ranking and evaluation of important ideas, see c. (2) above, are usually accomplished by simple voting procedure.

e. *Presentations.* At key points the modeller / reflector provides structured reflections back to the group. This becomes increasingly important with the development of complex feedback (system dynamics) models. Anderson and Richardson emphasise that these are important opportunities for the modelling team to recap dynamic insights, to capture and hold ideas, or simply to clarify for the group what has occurred during earlier stages of the process.

7.5 The Role of Causal Loop Diagramming in IISD

The systems thinking / system dynamics methodology described above suggests a significant departure from that taught at, say MIT, and as advocated by Sterman (2000) in his comprehensive tome on the subject. The latter is reliant on the development of causal loop diagrams from the earliest stages of conceptualisation, both in the divergent and convergent thinking tasks described at sub-para c., in 7.4 above.

A considerable part of the systems thinking and system dynamics literature (Goodman, 1989; Kim and Senge 1994, Senge 1990…) advocates the use of causal loop diagrams and high-level systems archetypes, and the *Systems Thinker* (Kim, et al., 1990 – 2001) is dedicated to advancing the use of causal loop diagrams. Causal loop diagrams can be useful when used, as conceptualisation tools, particularly in conjunction with stock / flow diagrams to depict the factors which influence flows (rates) or the factors to be considered in the calculation of auxiliary parametric values. Causal loop diagrams suffer from a number of significant deficiencies. Richardson (1986) originally raised a number of concerns about causal loop diagrams. The debate about their use continues. In this tutorial, a more robust alternative is offered. A tool and techniques for robust analysis of causal loop diagrams is at Chapter 11.

By themselves causal loop diagrams do not differentiate between stocks (levels) and flows (rates), and totally neglect any consideration of dimensional integrity. For this reason, when causal loop diagrams are used it is strongly suggested they be used in conjunction with stock and flow diagrams. Those who advocate use of causal loop diagrams, particularly during the early stages of problem conceptualisation apparently assume that there is a high degree of familiarity with, or understanding of, the causes underlying extant problems. From the cases studied in Chapters 3 and 4, there was no evidence to support such an assumption. Indeed, there was considerable evidence to suggest that there was little such understanding even amongst those who should have known most about the problem situations. For this reason, and just because causal loop diagramming is popular, does not mean we should assume it represents best practice.

Best practice in causal diagramming is embodied in the form of influence diagram developed by Coyle (1996: 18-83). This will be discussed below at 7.13 and at Chapter 11 where an advanced causal analysis tool, designed to overcome many of the shortcomings of causal loop diagrams, is described. This is not meant to suggest that causal loop diagrams do not have a role in the system dynamics method. They do, mainly as a means of summarising the main causal feedbacks. It is argued that those trying to find out about a problem situation would not be equipped to generate such summaries until they have spent considerable effort developing an understanding of the problem. They will be unable to do so until they are highly familiar with the problem. That familiarity only comes much later.

A systems archetype, expressed as a causal loop diagram, is a set of hypotheses about a given problem situation. In order to establish validity of the systems archetype in relation to the problem situation at hand, each separate hypothesis must be validated. This is not a task for those inexperienced in systems thinking and system dynamics. Again caution is suggested. As far as IISD is concerned, causal loop diagramming will only be used as a device for summarising major feedback mechanisms, and only when the problem situation is very well understood.

7.6. Accommodating Stakeholder Perspectives and Preferences

Psychological make-up creates individuals' preferences for particular types of reasoning. This can influence how knowledge elicitation and problem conceptualisation are approached, and how managers and decision-makers are engaged. See Figures 2-3 and 2-5. During each stage of problem conceptualisation and investigation of individual stake-holdings, it is important to remain cognisant of preferred modes individuals have for gathering and processing information. This was discussed at 6.23.

The preferences and choice styles described at 6.23 cannot be ignored simply to make use of elicitation and conceptualisation workshops, or group modelling techniques, that are convenient for the modelling support team, regardless of how justified the techniques might seem. The key to conceptualisation is accommodation of stakeholder perspectives and choice styles. See 6.23.

Experience gained from cases described in later chapters of this dissertation is that few people feel comfortable with a prescriptive approach to problem conceptualisation. It is a real challenge to accommodate different stakeholder views through the elicitation process, accommodate preferences for different types of information whilst presenting information in ways with which stakeholders are comfortable.

Checkland and Scholes (1999) make a similar observation about how comfortable stakeholders feel about using rich pictures. This is because some people do not have very good drawing skills. So, rich pictures developed from Microsoft® Clip Art can be an alternative to hand drawn rich pictures (Williams 2000: 643). Clip Art rich pictures, such as shown below at Figure 7-2, can be useful in encouraging the use of SSM, which might otherwise be denied to stakeholders because of their inability, or reluctance, to draw.

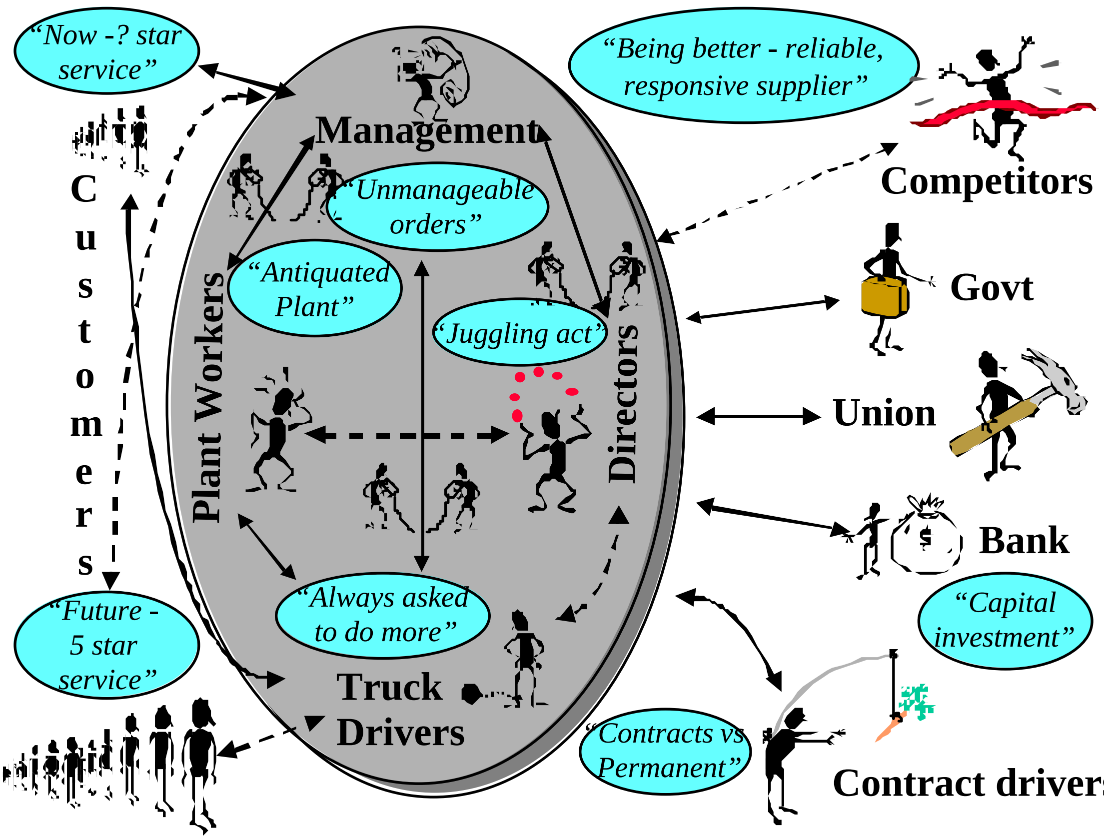


Figure 7-2. Clip Art Rich Picture of *ThreeTwoOne's* Problem Situation (1)(2)

Notes:

1. Clip Art rich picture illustrating the flow of communications in *ThreeTwoOne* between the company's internal and external entities.
2. *SSM Root Definition: ThreeTwoOne* is a privately owned, limited liability commercial system which takes locally available materials and uses plant and equipment to produce concrete, which is mixed in direct response to customer phone

orders and delivered by truck to individual customers at building sites in the local area.

The formal process of knowledge elicitation must accommodate choice styles defined above at 6.23. The elicitation and problem conceptualisation processes involve progressive identification, definition, and testing of stakeholder perspectives, values, and ingrained assumptions. Some people find this threatening and can become defensive, see Figure 2-3, or may even withdraw from the process. It cannot be assumed that stakeholders will always be willing and cooperative. If any stakeholder becomes reluctant, or is expected to be so, it may be necessary to revert to engaging them in one-on-one discussions or interviews.

Effective knowledge elicitation should lead to identification of areas of agreement, contentious issues, misunderstandings and potential for misinformation. From individual stakeholder views an aggregated, or summary, view can be developed. But, a note of caution is needed here. Any amalgamation, or reification, of cognitive maps should be done with intimate involvement of stakeholders, noting that cognition belongs to individuals and not to organisations. See 4.15. By contrast, and by definition, concept maps are an amalgamation of views. Disparate views are moderated when group members work together through their contributions to the process of developing concept maps.

7.7 Working with Subgroups to Elicit Their Views of the Problem Situation

The general problem situation, as depicted at Figure 7-2, is further investigated by engaging individual subgroups in conceptualisation of the problem as it appears to them. The subgroups formed are:

a. Directors.

b. Managers.

c. Plant workers.

d. Truck drivers.

The general narrative describing the problem situation is augmented by a set of additional observations, which impact upon each subgroup. These are:

a. <u>Directors</u>. *ThreeTwoOne's* directors provide the guiding input to how the company will run. Further observations are:

(1) As a long-term strategy to improve the company's viability, traditionally directors have been given a bonus based on the company's annual profit, as shown in the annual report.

(2) A couple of the directors are nearing retirement. These directors are advocating maximising profit in preference to investing in new trucks, plant and equipment that the managers claim are desperately needed.

(3) Other directors recognise that to be profitable in the long term, a 'competitive edge' is essential. They are advocating investment in:

(a) New information technology customer service systems intended to better capture customer orders and meet customer expectations.

(b) At least two new trucks, or as many as are fully justified by the consultant's report, when it is delivered.

(c) Automated plant.

(d) Training of management personnel in customer relations and management techniques.

(4) Some directors see managers currently employed are ineffective and are advocating replacements be found.

b. Managers. Managers at *ThreeTwoOne* schedule the plant's operation based on customer requirements and aim to have the plant operate as efficiently as possible. Staff includes the site supervisor, operations manager, operations manager and clerical staff. Observations pertinent to this group are:

(1) Managers are always very busy. They say they are overworked.

(2) Plant operators and drivers continually claim they are not given sufficient time to do their work. Management expects them to react immediately to every crisis, when managers not forecasting incoming orders create many crises.

(3) Managers would prefer all workers to be members of the one union, Workers United. They would prefer to deal with only one union.

(4) The drivers' initiative to become part of the Transport Workers United

union is treated with a good deal of distain and distrust.

(5) Managers are seeking to improve operational efficiency, and this could mean redundancies.

(6) Managers would prefer to use owner-driver contractors regardless of the short-term premium paid. They believe that by negotiating longer-term contracts, the cost penalty could be overcome and a better deal could be achieved. This is perceived as being more cost effective. It would also provide an opportunity to get rid of militant drivers.

c. Plant workers. Workers at *ThreeTwoOne* perform other duties such as operating the batch plant, servicing and repairing equipment on-site. Under direction of management staff they manage various aspects of plant operation. Observations are:

(1) Priority is given to delivering concrete, and little consideration is given to plant workers. If there are rush orders, plant workers often have to work through scheduled breaks, or start early. They are expected to be reactive to everyone else's priorities.

(2) If an equipment failure or delay occurs, they are the first to be blamed, particularly when trucks queue up for concrete when none is ready.

(3) There have been a number of *ad hoc* meetings about the operation of the plant. On a couple of occasions, they were not notified until it was almost too late to attend.

(4) Workers and truck drivers are currently members of the same union, Workers United. The union has not been very helpful in recent months. The drivers are seeking to become part of the Transport Workers United. As a result, workers believe they will be left to fend for themselves.

(5) Managers are seeking to improve operating efficiency, and this could mean redundancies.

d. Truck drivers. Truck drivers at *ThreeTwoOne* perform what is considered to be the most prestigious job. However, they are not a united group. Observations relevant to this group are:

(1) There are permanent employees who drive the company owned trucks.

(2) During periods of high workload, owner-drivers are brought in to assist. These drivers work on short-term contracts.

(3) Contract drivers are not really trusted by the permanent drivers.

(4) There are rumors that, starting in the next financial year, the government will be encouraging out-sourcing by providing rebates to companies who use owner-drivers on contract.

(5) There have been a number of *ad hoc* meetings about the operation of the plant and meeting customer expectations. The truck drivers see themselves as providing a vital interface to the customers and so believe they should have the major input to such meetings. Consequently, other groups have left such meetings feeling their views have not been represented fully.

(6) Permanent truck drivers are currently members of the same union as the workers, Workers United. These drivers are seeking to become part of the Transport Workers United.

(7) The drivers do not fully understand the directors who, on one hand, are saying that they intend to buy a number of new trucks, whilst on the other are rumoured to be planning to use more contractors.

7.8 Impediments to Reaching a Shared Understanding of the Problem Situation

Getting to the heart of a problem situation and developing a shared understanding is not a simple task. Various impediments present along the way. To make the tutorial more realistic, and to reflect the real-life situation, the following hidden agenda are given to the secretaries of each group. They are briefed that they are not to make others in the group aware of their additional sinister intentions. Hidden agenda, by subgroup, are:

a. <u>Secretary of directors subgroup</u>. Unbeknown to other directors you have decided to cash in all your shares in the company at the end of the year and retire to Fiji. You feel little loyalty to the company since they forced your colleague, Harry Watkins, to retire as Managing Director. Your attention is simply focussed on maximising the share price over the next six months. You are concerned that any big capital expenditure for plant upgrading or any negotiated increase in salaries will be looked at adversely by the marketplace. On the other hand, buying extra trucks in the short term will be good for marketing image and good for share prices. If the others get wind of your plans you can be sure that they will treat any suggestions by you with distrust.

b. Secretary of managers subgroup. Your annual bonus is based on the size of the net profit before tax for the year. You are concerned that any write-off of technically obsolete plant (which still has a substantial residual value in the balance sheet but is, in fact, worthless) will severely cut into profit and, hence, your bonus. You have already decided to take early retirement as soon as you get your annual bonus. Your hidden agenda is simply to push sales and cut costs as hard as possible in the immediate future, without regard for longer-term costs. If the others get wind of your plans you can be sure that they will treat any suggestions by you with distrust.

c. Secretary of plant workers subgroup. You, and your workmates, are sick and tired of being blamed for every shortcoming when you know that it's the drivers who have been lazy. All the new planned expenditure seems likely to go on more trucks, but if management simply tighten up on discipline the problems of not being able to meet customer expectations will be solved. On the other hand, you desperately need new equipment, but that will be set aside if the directors decide to buy extra trucks. Your aim is to gain support for maximum expenditure on new plant and equipment. You believe the expenditure on new trucks is a total waste. But to argue for new plant rather than supporting the planned expenditure on new trucks is likely to cause a problem with the Workers United union, because such a strategy could reduce the total number of employees at *ThreeTwoOne*. If the others get wind of your hidden agenda you can be sure that they will treat any suggestions by you with distrust.

d. Secretary of truck drivers subgroup. All drivers are currently members of the Workers United union. You are shop steward and have ambitions to get a full time position in the union. You are aware that the Transport Workers United union is starting yet another push to gain a foothold in this industry sector.

> Some of your workmates feel that the Workers United union has let them down and could be sympathetic to a Transport Workers United push. You feel that it is important that the Workers United be seen to stand up to management, at least until the election in three months time. Obviously you have to keep your personal intentions quiet for the moment. If the others get wind of your plans you can be sure that they will treat any suggestions by you with distrust.

7.9 Results of Workshops Conducted with Each Subgroup

Typical concept maps produced as a result of workshops are:

a. Figure 7-3 Problem Situation as Perceived by *ThreeTwoOne's* Directors.

b. Figure 7-4 Problem Situation as Perceived by *ThreeTwoOne's* Managers.

c. Figure 7-5 Problem Situation as Perceived by *ThreeTwoOne's* Plant Workers.

d. Figure 7-6 Problem Situation as Perceived by *ThreeTwoOne's* Truck Drivers.

In the classroom workshops conducted at the Australian Defence Force Academy, when each map was completed, or when the allocated time of 50 minutes expired, the group was given an opportunity to verify that inputs had been properly recorded. A nominated spokesman then formally explained the content and structure of the map to the group in a reflective process. This spokesman then presented the problem situation perceived by his / her group to the whole class. This is a deviation from the procedure, described at 7.4 above, intended to reveal as far as possible the considerations of each of the other groups. Production, in 50 minutes, of maps containing this level of detail is consistent with experience of Eden and Ackermann (1998a: 303-320), noting Australian Defence Force Academy students work predominantly from set narratives in this exercise. In practical situations, the procedure described at 7.4 is followed.

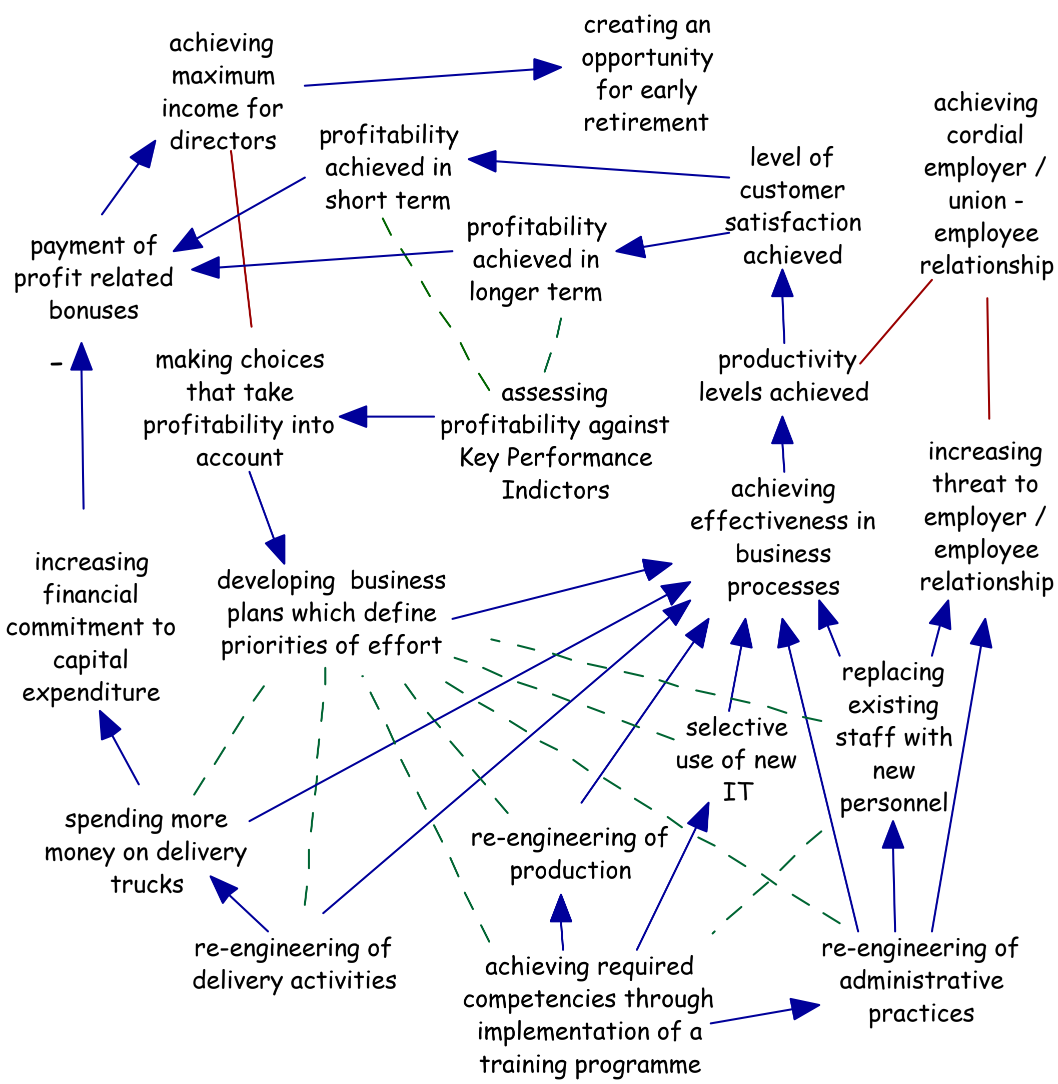


Figure 7-3. Problem Situation as Perceived by *ThreeTwoOne's* Directors

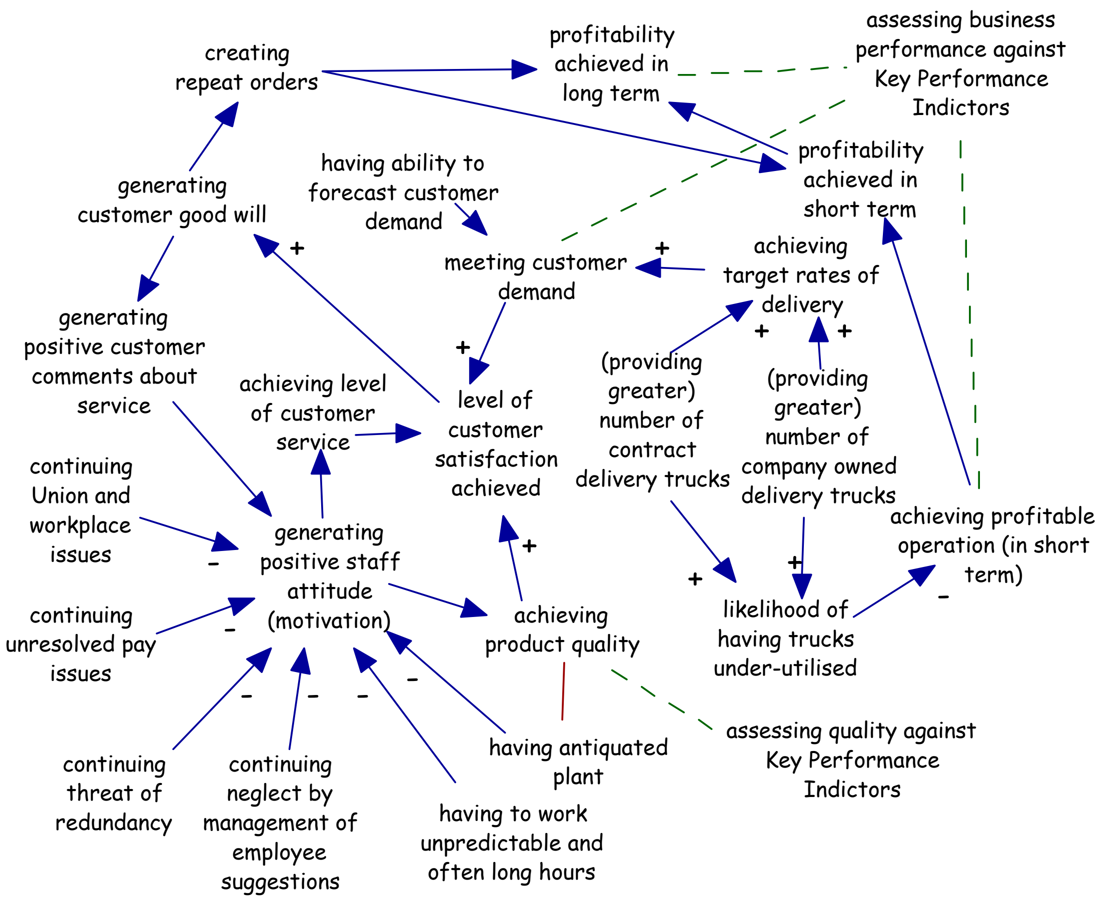


Figure 7-4. Problem Situation as Perceived by *ThreeTwoOne's* Managers

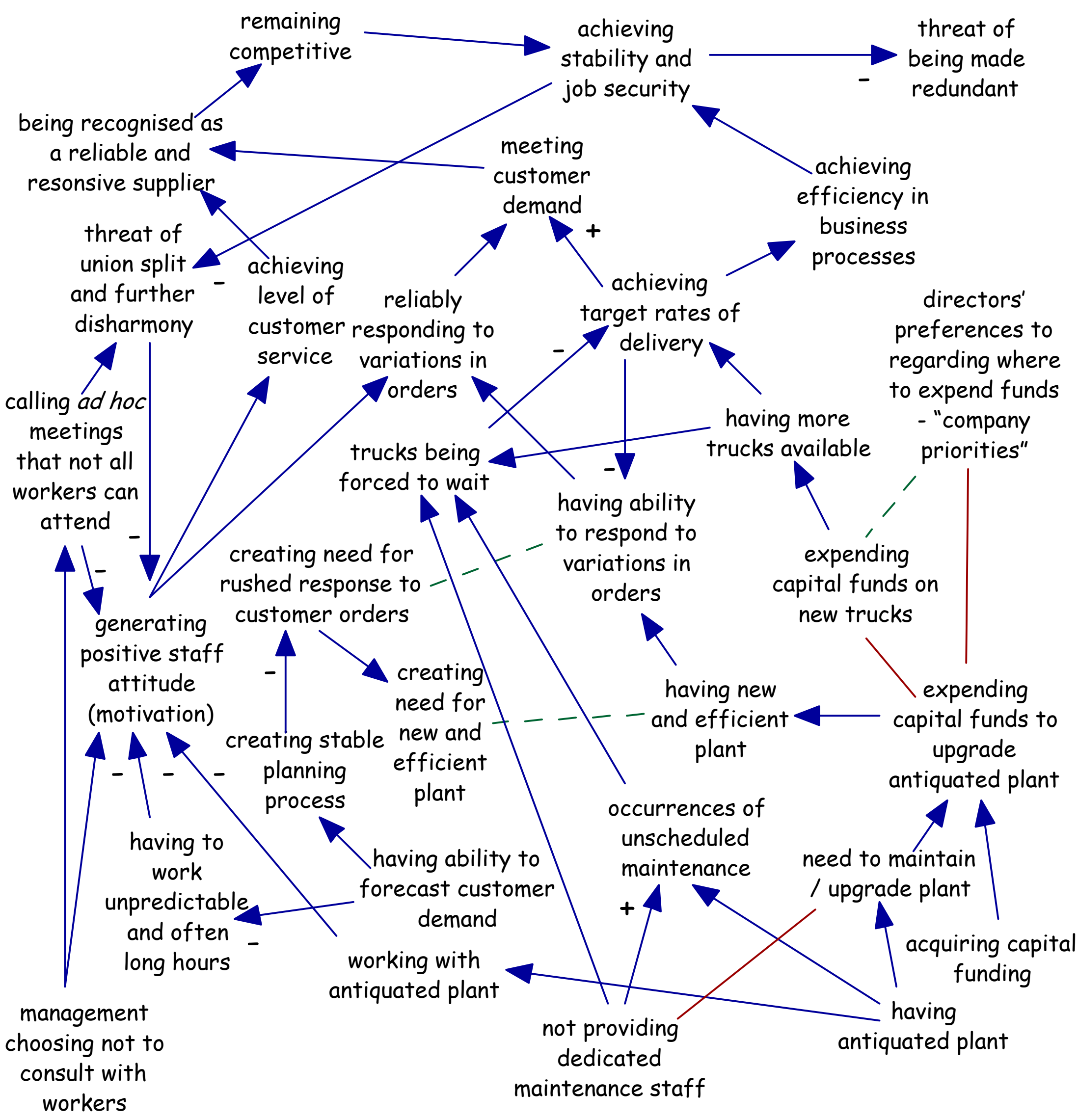


Figure 7-5. Problem Situation as Perceived by *ThreeTwoOne's* Plant Workers

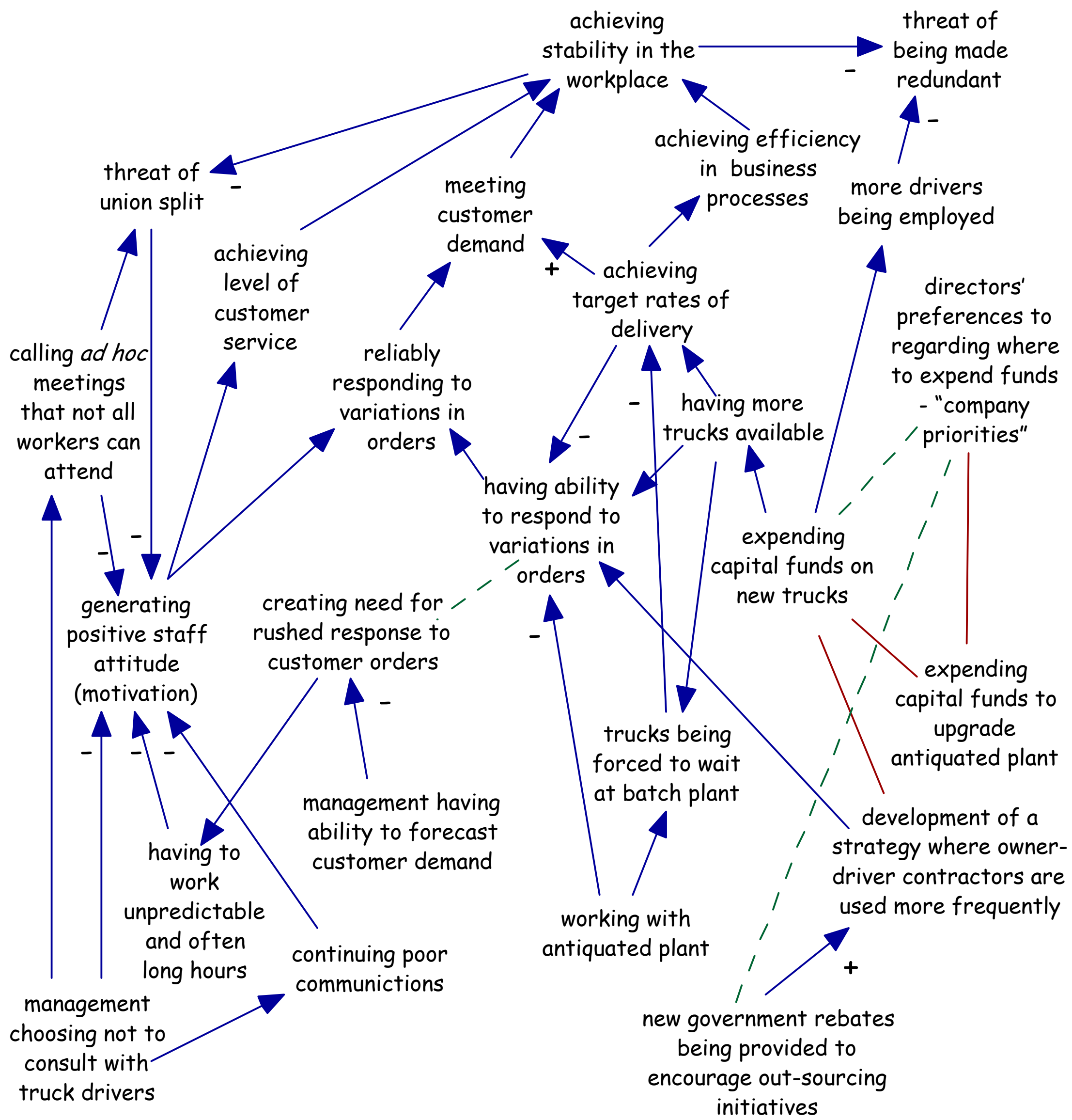


Figure 7-6. Problem Situation as Perceived by *ThreeTwoOne's* Truck Drivers

7.10 Validation of Concept Maps.

Each map must be validated. It is preferable that validation be conducted within the subgroup because the validation process will draw even further on the assumptions of individuals and their perspective. It is wise not to make these assumptions public if a likely consequence is embarrassment to the individual.

If a nominal group process is used to support the subgroups then concepts from subgroup maps are progressively incorporated into the nominal group map. In this case, the subgroup workshops are used more to generate ideas, even though a product of that activity is a separate subgroup map. However, validation of the nominal group map remains critical. To enable validation to occur, questions will need to be posed to each of the subgroups to seek clarification of how and why they seek concepts linked together. On completion of the nominal group map, validation will be needed to ensure the map truly represents the views of the members of the nominal group. This validated map then forms a set of hypotheses, which form the basis for further investigation.

The validation process involves pair-wise consideration of causality, as shown in Table 7-2, below. In this example, focus is brought to bear on the concept *generating positive staff attitude (motivation)* in Figure 7-6.

Focal Concept	Direction and Type of Link	Linked Concept	Polarity of Link	Comment
generating positive staff attitude (motivation)	←	*having to work unpredictable and often long hours*	Negative	Drivers are concerned that when rush orders arise they are the last to go home. They always have to deliver today. They often miss lunch and afternoon tea breaks as a result. They are tired of the unpredictability.
	←	*continuing poor communications*	Negative	Drivers are concerned that they are always the last to be told of rush orders because they are often on the road when the orders come in. Further, because they are frequently away from the plant there are many things that they are simply not told about.
	→	*reliably responding to variations in orders*	Positive	Everybody feels the same, if they were better motivated and felt happier about their treatment by *ThreeTwoOne*, they would be more inclined to 'pitch in' when it gets busy.
	←	*(creating) threat of union split*	Negative	Continual talk of a change in union allegiances is worrying.
	…	…	…	…

Table 7-1 Schema for Validating Causal Linkages

Concept maps are validated, by following the schema depicted in Table 7-1. The first step is to ensure each concept is written as a call for action. If an abbreviated statement has been used in the concept map, it is necessary to fully state the concept as a call for action. For example, *threat of union split* in the fifth row should be restated as *(creating) threat of union split*. It is essential to make this type of change to obviate ambiguity and confusion in subsequent interpretation. The next step is to validate the causal direction and type. Most frequently this reveals links where the direction of causality has been incorrectly interpreted, and less frequently where the type of causality is incorrectly recorded. In this regard, the explanation in the 'Comment' column is most useful for recording the rationale used for determining the direction of causality to be shown in the final version of the map. These 'Comments' will also be valuable later, after strategy implementation, to gauge how effective the intervention has been. That is, the 'Comments' can be used as a checklist of things that should have been corrected by implementation of the chosen strategy.

7.11 Production an 'Executive Summary' Concept Map

The process of producing an 'Executive Summary' concept map follows from the creation of the subgroup maps. The nominal 'executive' group is provided with concepts from each of the subgroups. For this activity, the group modelling workshop methodology developed by Anderson and Richardson (1997) is followed. See the description at c. (1) in 7.4, above. The executive summary is <u>not</u> produced with the aim of reification of subgroup maps. It is produced with the intent of determining where to apply management effort. During the development of the executive summary concept map, decisions are taken to selectively include or exclude concepts, to restate them and to work at a higher level aggregation. The product is a single map which will form the basis for development of an influence diagram and, if necessary, system dynamics modelling simulations.

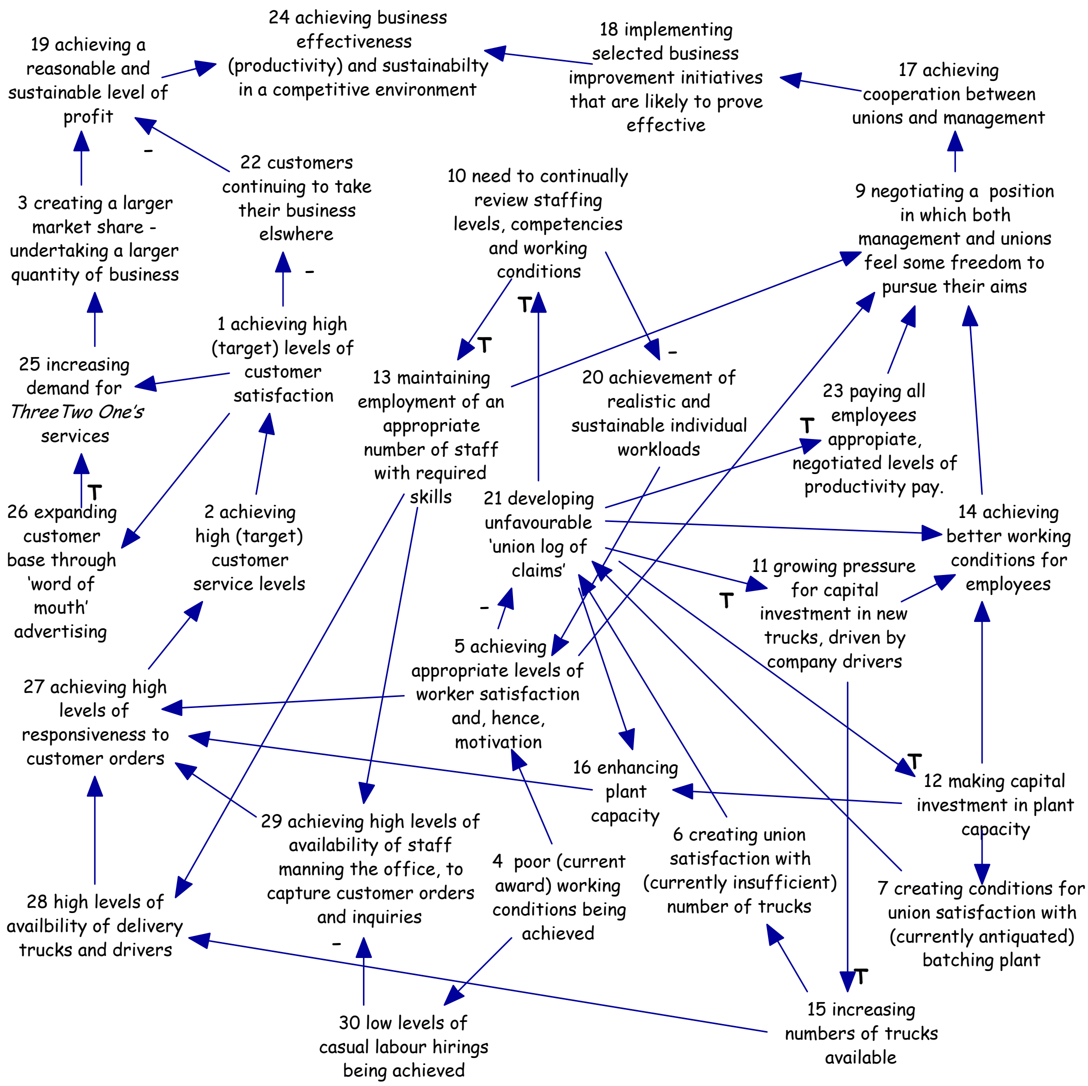


Figure 7-7. Executive Summary Concept Map (1)

Notes:

1. 'T' denotes temporal nature of causality, that is, an unspecified or unknown delay before the effect is produced.

7.12 Analysis of Executive Summary Concept Map

As any concept map is drawn, the more important concepts should be placed at the top. Subgroup maps differ in terms of what is considered more important. In development of the map at Figure 7-7, a conscious choice was taken to focus on achieving long-term viability of the company (Concept 24). This cannot be achieved without making profit (Concept 19), having implemented a number of improvements (Concept 18) and having a workable relationship between union and management (Concept 17). Clearly *ThreeTwoOne* has to do something fairly quickly. Following down the left hand side of Figure 7-7 it is intuitively obvious that high levels of responsiveness to customer orders

(Concept 27) is a foundation to all above and on the left side of the concept diagram. In turn, the ability to achieve this responsiveness is determined by a combination of:

a. High levels of availability of delivery trucks and drivers (Concept 28).

b. Achieving high levels of staff manning the office, that is, to capture customer orders and respond to inquiries (Concept 29).

c. Enhancing plant capacity (Concept 16).

d. Achieving appropriate levels of worker satisfaction and, hence, motivation (Concept 5).

All of four are critical to achieving *ThreeTwoOne's* goals, as is achieving cooperation between unions and management. Indeed, Figure 7-7 could be re-drawn to provide a broad approach in an intervention to correct *ThreeTwoOne's* problems. See Figure 7-8.

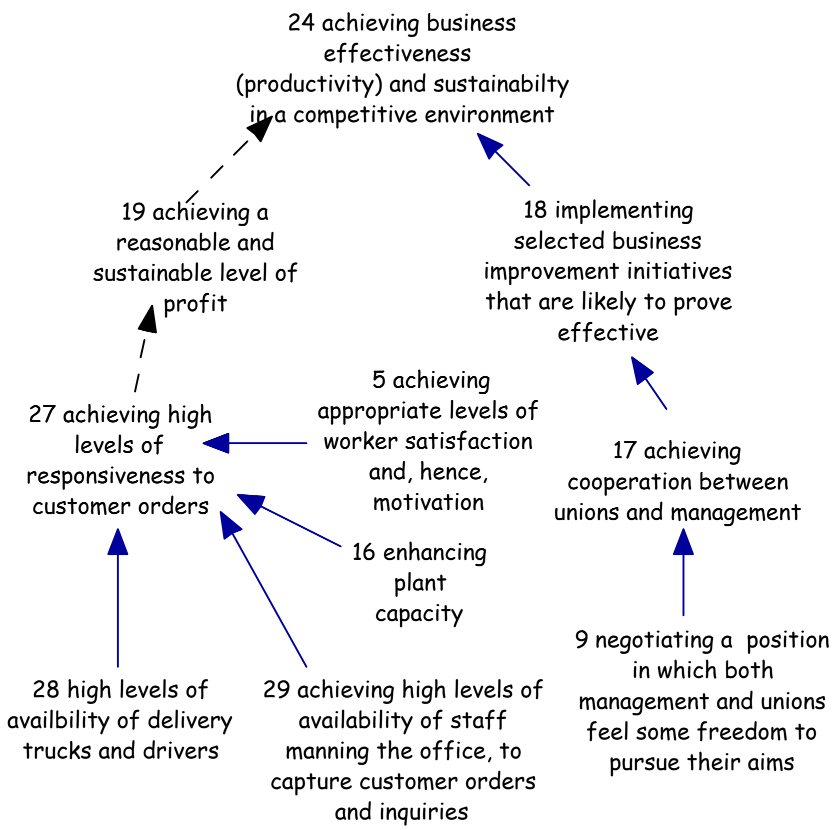


Figure 7-8. Simplified Executive Summary Map (1)

Notes:

1. Dashed arrows signify detail has been omitted.

At this stage when such a conceptual model of the problem is produced, the normal reaction from students is that this is obviously the problem that *ThreeTwoOne* faces, and that we could have gone directly to this… "why did we need to go through such a detailed systematic process?" The answer lies in Figure 2-2. It seems incongruous that students will happily spend 20, or more, hours building a sophisticated quantitative model that addresses the wrong problem, or ignores some important aspect. Most frequently omitted, or misunderstood, is the level of staffing needed in *ThreeTwoOne's* office (Concept 29). Near to full-time manning is essential if customer orders are to be captured, noting that customers will go to a competitor rather than make a second phone call that might go unanswered. One or two hours spent on problem conceptualisation has been found to reduce the modelling time by up to one third.

The analysis associated with the Simplified Executive Map, Figure 7-8, guides us to where some form of quantitative modelling might be useful. It is practical to build a model which takes into account the receipt and handling of customer orders, the mixing of concrete, and delivery. This will provide valuable insights into capital investment strategies and likely impact on ability to respond to customer orders. Of course, it has to be assumed that worker satisfaction can remain at a workable level. Worker dissatisfaction must be addressed as part of an overall package. Similarly, the overall package must take into account the subgroup concerns as expressed in their concept maps, Figures 7-3, 7-4, 7-5, and 7-6.

The next step is to build an influence diagram, which depicts the main influences upon:

a. receipt and processing of customers orders,

b. mixing of concrete in response to orders, and

c. delivery activities.

7.13 Developing an Influence Diagram

The influence diagram becomes an indispensable hypothesis for subsequent investigative discussions and, with amendment by the group, or at least by agreement among the principal stakeholders, becomes the basis for subsequent model development. Concept maps, or other outputs from knowledge elicitation, have to be converted into an influence diagram (Coyle, 1996) as the next step in IISD. Conventions for influence diagramming are shown at Figure 7-9, below.

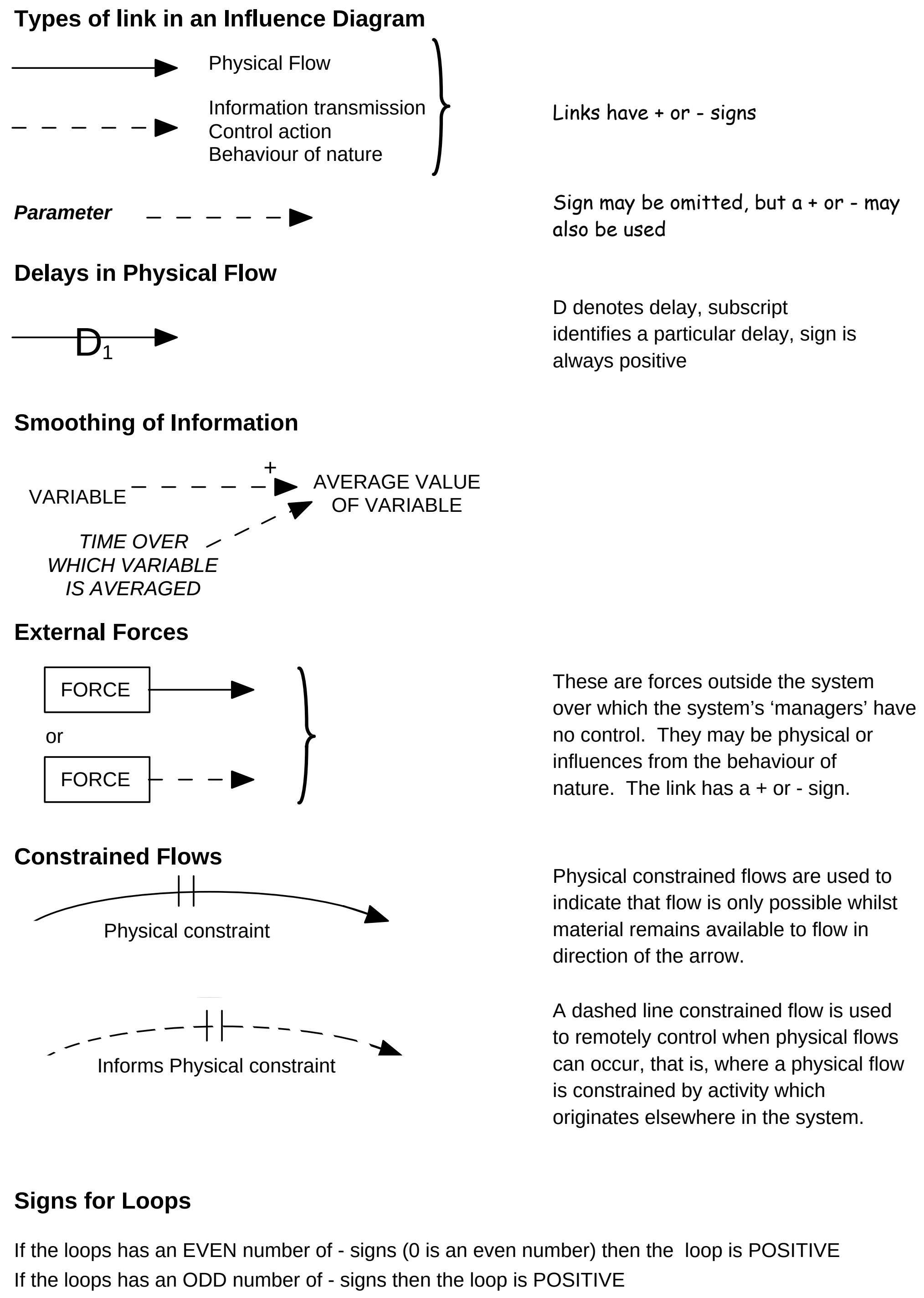


Figure 7-9. Overview of Coyle's Conventions for Influence Diagrams

Building influence diagrams is necessary regardless of any subsequent choice to develop quantitative models. This form of influence diagramming is used because it has the following major advantages over other forms such as causal loop diagramming:

a. *If the influence diagram is properly drawn, the simulation model can be written from it without a separate stage of flow charting.* In effect, the influence diagram and simulation model are simply two versions of the same model; one written in arrows and words, the other in equations and computer code. This property is of fundamental importance in system dynamics as it gives rise to some powerful practical consequences (Coyle, 1996: 11-12). Coyle uses a number of diagramming ‘common modules’ in development of influence diagrams. These are equivalent to blocks of code written in the high level computer programmes COSMIC™ or COSMOS™. If applications such as Stellar™, Ithink™, or Powersim™ are used, stock / flow diagram equivalents to those common modules must be understood. Equivalents, which provide the link between influence diagrams and stock / flow dynamic models are summarised at Figure 7-10, below. The relationship between causal influence diagramming and simulation model building is discussed further at Chapter 13.

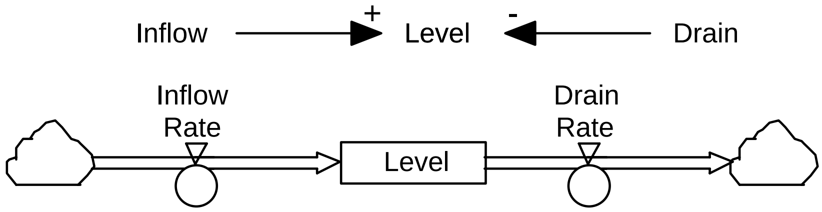
b. *The fact that the model exists in two equivalent forms of a diagram and a set of equations is a powerful aid to thinking about and understanding a problem* (Coyle, 1996: 13).

c. *Having two equivalent forms of diagram and a set of equations is a powerful aid to effective communication.* The importance of communication was discussed at 2.20.

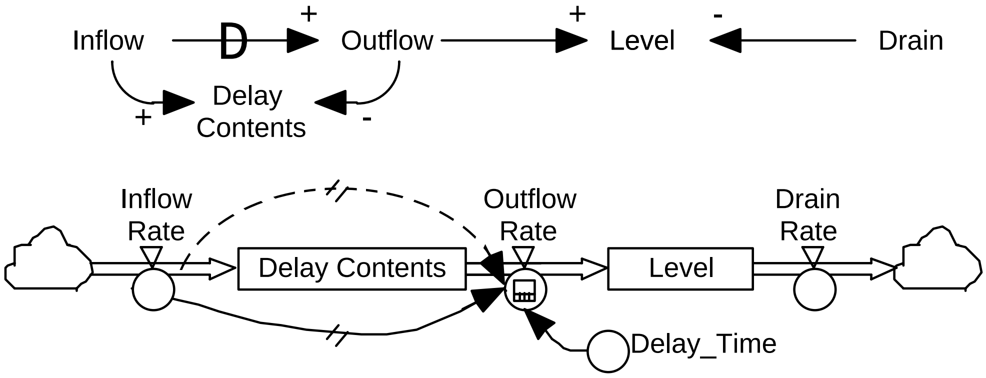
d. *If the influence diagram is properly drawn, problem analysis and, often, strategy development is possible without resorting to simulation modelling.*

In Figure 7-10, the upper diagram under each group heading is Coyle’s common module notation and the corresponding lower diagram, is the stock and flow equivalent.

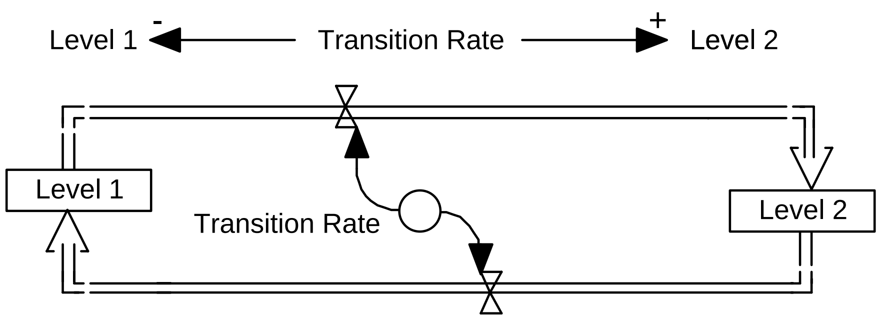
A. Simple Inflow / Outflow



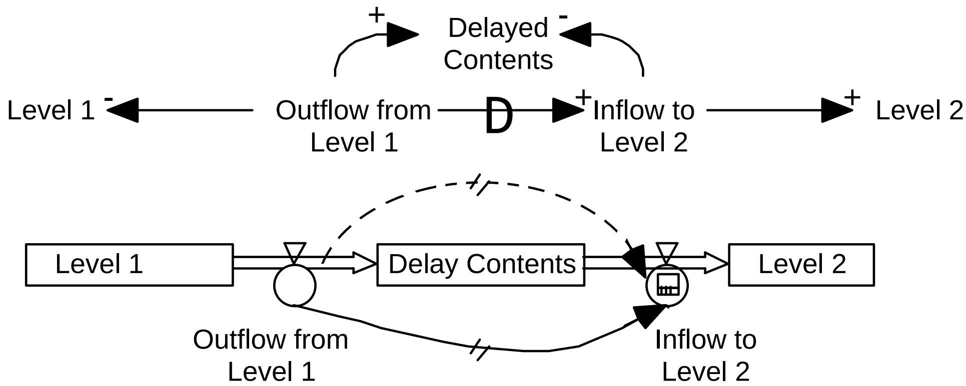
B. Delayed Inflow



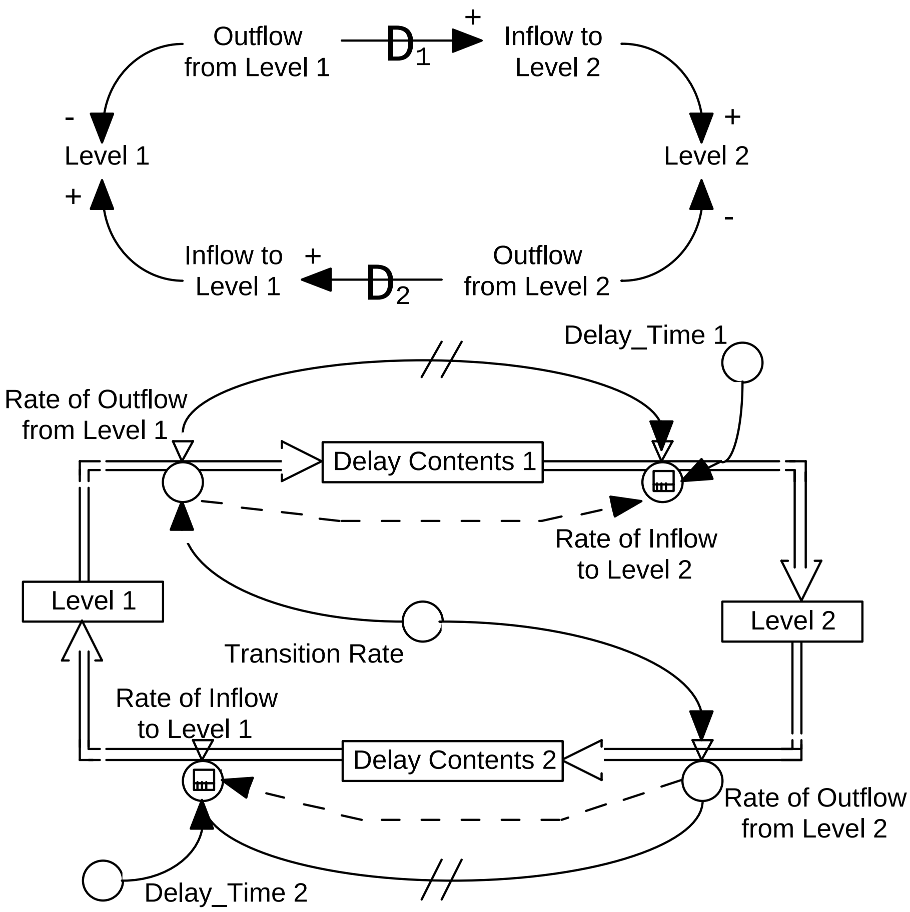
C. Transitional Flow (Reversible)



D. Delayed (Irreversible) Transitional Flow



E. Delayed (Reversible) Transitional Flow



F. Proportional Control

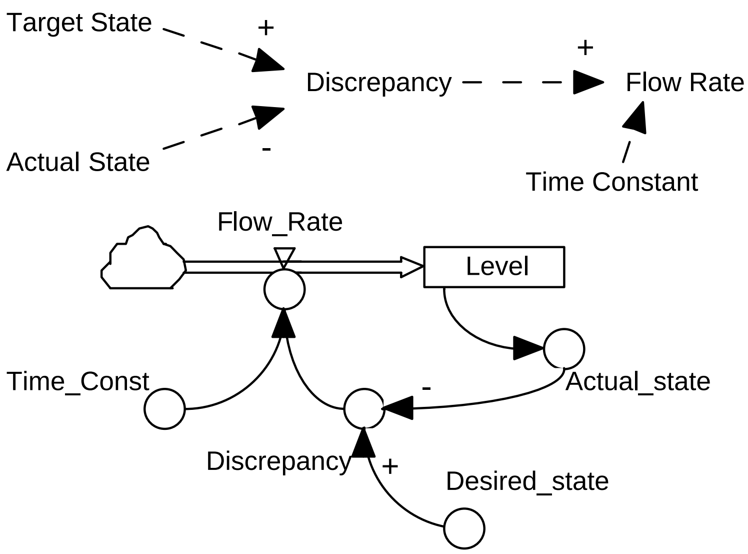


Figure 7-10. Influence Diagram 'Common Modules' and Stock / Flow Equivalents

Stakeholders must have the influence diagramming conventions explained to them in terms they understand. This explanation must be extended to cover any influence diagrams produced. This is essential to enable their involvement in the revision and progressive refinement of influence diagrams.

Through influence diagramming, dominant mechanisms are identified and the links are mapped for all to see, appreciate, challenge, and ultimately accept or reject. Through further cycles of analysis, strategic assumptions are critically reviewed until the diagram is moderated to a form acceptable to the nominal group of stakeholders. The basic influence diagrams for the three sub-models identified, are at Figures 7-11, 7-12, and 7-13, below.

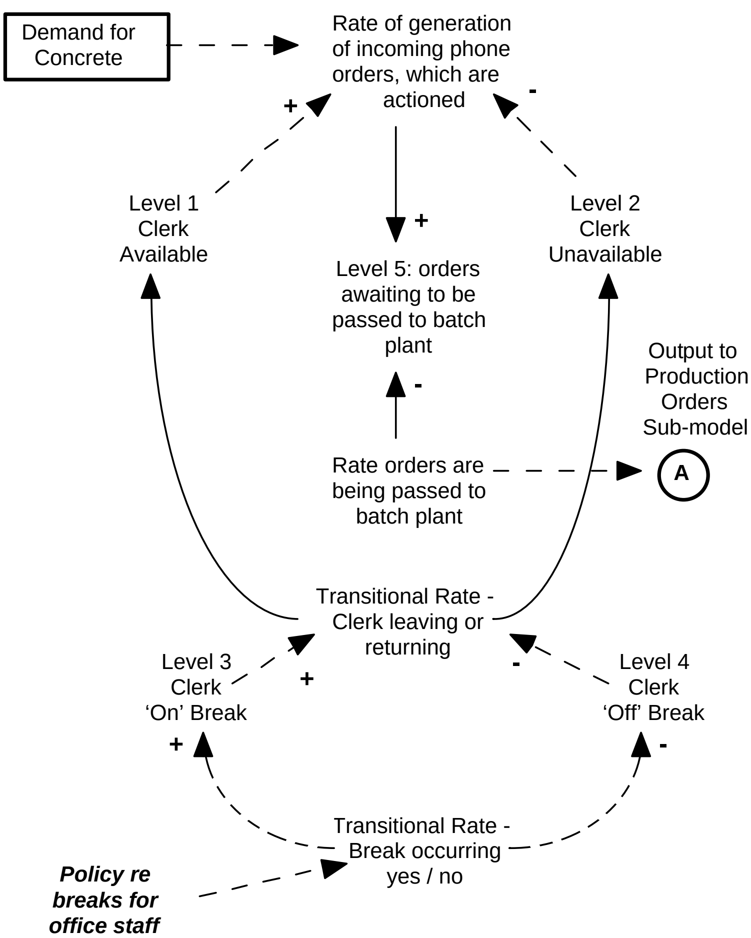


Figure 7-11. Influence Diagram for Clerical Office Sub-model

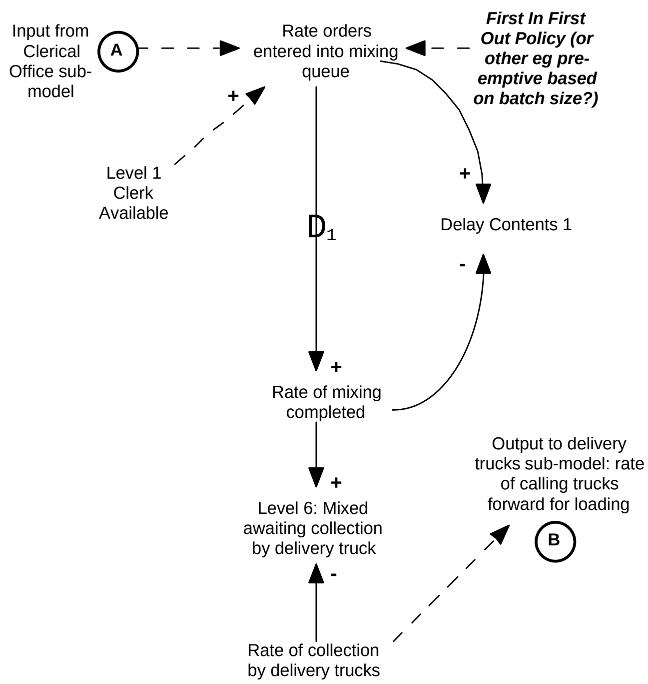


Figure 7-12. Influence Diagram for Production Orders Sub-model

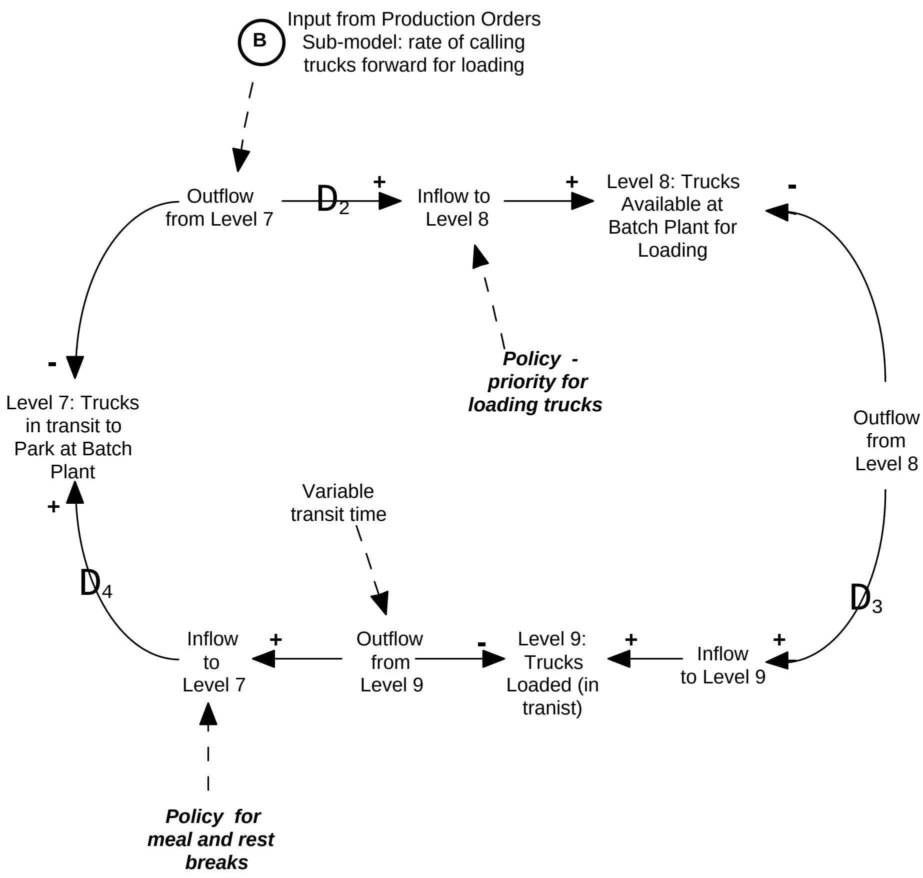


Figure 7-13. Influence Diagram for Delivery Trucks Sub-model

7. 14 Thinking the Problem Through in Detail Using Influence Diagrams

It is considered absolutely essential that the problem be comprehensively analysed using influence diagrams before the computer is turned on. The influence diagrams immediately provide certain insights about the structure of the problem, such as:

a. what the external forces are, and where they act;

b. which are stocks and which are flows, and the relationship between them;

c. how the stocks and flows are connected;

d. which are material flows and which are the information flows;

e. what the current system management policies are, and where they impact;

f. where the current system management policies impact; and

f. where the feedback loops occur.

A number of observations can lead to remedial strategies without simulation modelling:

a. In Figure 7-11, it is intuitively obvious that to have the clerical office manned as continuously as possible is important, both to capture and action incoming orders, and to pass them to the batch plant operators who are responsible for having the orders mixed.

b. Making changes to system policies, shown in bold italics, offer the opportunities to make significant impacts. We might focus on those policies that are closely related to delays in feedback loops, such as in Figure 7-13.

To understand the dynamics, particularly of the complicated queue structure depicted in Figure 7-13 demands building a dynamic simulation model. So, the next stage is to convert the influence diagram into such model. In this case, building a dynamic simulation model is essential.

7.15 Dynamic Modelling

System dynamics models are built on the basis of influence diagrams, and models are built in modular form as suggested by the diagrams at Figures 7-11, 7-12 and 7-13. Building models in a modular form helps in developing confidence that errors of logic are not being introduced. For example, the output from the Clerical Office sub-model is the rate at which orders are passed to the batch plant. This output can be readily compared with patterns derived from the historic data already collected. Such data and observations form the basis for establishing the reference modes of systemic behaviour. It is against these reference modes that the outputs from sub-models are tested. This forms the basis of establishing sub-model validity. As the simulation model takes shape and is validated, clarity of understanding grows further. System dynamics modellers usually exploit this phenomenon by starting with small models, which are then expanded as necessary and always in a controlled way. Stakeholder suggestions and views are solicited progressively and iteratively. These views based on their knowledge and experience are continually tested by comparison with model behaviour. Where appropriate, changes are incorporated into models. Stakeholder involvement during both model development and validation is also crucial to building ownership of, and confidence in, strategies identified through these IISD activities.

Debugging system dynamics models is enhanced dramatically through the use of dimensional analysis. Few software applications support dimensional analysis. The exception here are COSMOS™ and COSMIC™. Dimensional integrity of models built using POWERSIM™, for example, is only possible if the model is build from a series of sub-models and each sub-model is manually checked for dimensional integrity. Frequently, dimensional analysis is overlooked both by students and professional practitioners. Indeed, it is a significant problem in the transition from qualitative to quantitative analysis. This will be discussed further at Chapter 12. A complete system dynamics model, which demonstrates *ThreeTwoOne's* activities in mixing and delivering concrete in response to customer orders, using various numbers of trucks, is at Annex B. A summary of observations derived from this modelling is at 7.16, below.

7.16 Flight Simulator

Once it is confirmed through building the system dynamics model(s) that the key parameters identified in the influence diagram are indeed the most influential, these are selected as the flight controls that management may use to test the likely effectiveness of their pet strategies. Dynamic behaviour is demonstrated and the model explained before it is made freely available for stakeholders and decision-makers for their experimentation. The flight simulator interface for the *ThreeTwoOne* ordering, mixing and delivery model is at Figure 7-14, below.

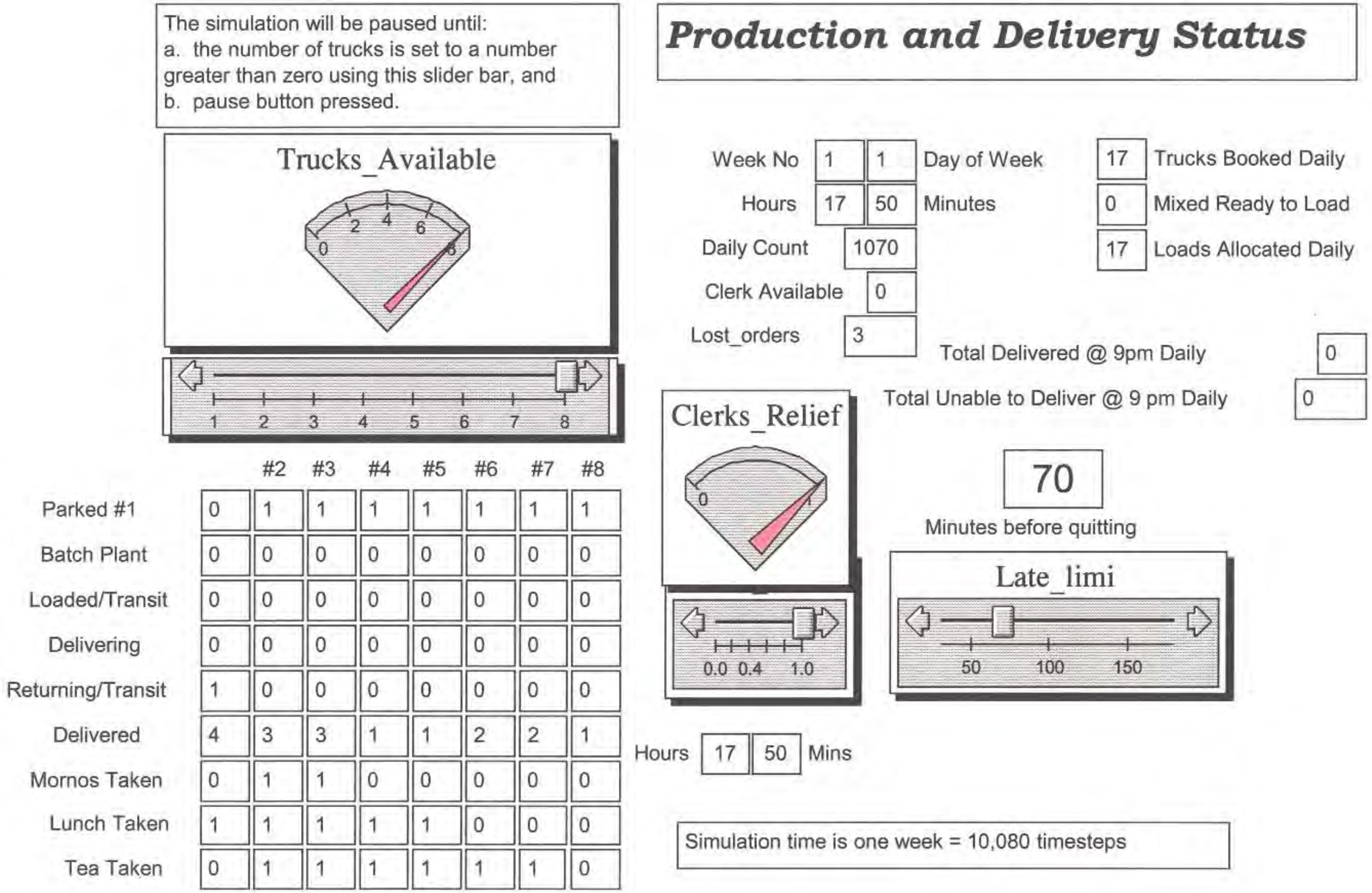


Figure 7-14. *ThreeTwoOne* Flight Simulator Interface

7.17 Play and Learn

Whilst the system dynamics model depicts a single view, it provides a powerful medium for learning about response to varying input. After a period of ‘playing and learning’ about systemic response, the role of feedback and delay, it is likely that based on newfound knowledge and experience, there are suggestions to rebuild that model. This is natural now that, in effect, through playing the players have gained the equivalent of many years of experience. Based on that experience, new strategies may be suggested for investigation. Observations from experimenting with the model, repeatedly running it and changing the availability of a clerical office staff, numbers of trucks, and the latest time orders could be accepted for delivery that same day, include:

a. The extent to which the clerical office is manned has a major impact on capturing and actioning incoming orders in response to customer demand. This was predicted from the influence diagram, but the extent of the effect was something of a revelation. Unacceptably high levels of lost orders resulted unless a relief was employed to take orders during scheduled breaks taken by the clerk. The ‘knock on’ effect of missing orders is that customer confidence suffers. When a relief was provided, lost orders were reduced by approximately one-third, but then a significant number of orders captured could not be delivered. This remained the case for numbers of trucks less than eight. When eight trucks were available, virtually all orders taken could be delivered the same day.

b. By changing the numbers of trucks available, and re-running the simulation, it is easy to see what the ‘optimum’ number of trucks might be. Seven seems to be the optimum number. But, players soon realise that the notion of optimisation cannot be divorced from a range of system management issues, such as:

   (1) What is the latest practical time that orders for delivery on that same day be accepted. If this time is made too long, drivers suffer because they are very late finishing. Further, this can change during the year depending on the season, noting that in warmer months builders are happy to work into the evening to lay concrete but it is impractical to do so in winter.

(2) A policy is needed to ‘hold over’ orders for delivery the next morning. This cannot be developed without customer involvement, meaning that the boundary of the currently defined problem space will have to be shifted to include customer input.

(3) The policy regarding when drivers can take scheduled breaks has a much greater impact than originally anticipated. Drivers on their way to delivering concrete are unable to take a break, but the timing of commencement of their return journey is currently the factor which determines whether they take a break or not. Once they commence their break they are unavailable to respond to demand for urgent deliveries.

c. Drivers regularly miss their scheduled breaks. It was found that they can miss as many as half their breaks and this was contributing to low morale. This was exacerbated by the regular occurrence that, upon return to the plant, they found they had to wait but did not have facilities available where they could enjoy a break. A suggestion was made that all trucks should be equipped with mobile phones or two-way radios to alleviate this problem. That is, drivers would have the facility to contact the office to determine if they were needed immediately or not. It is expected that when this aspect is modelled, the number of missed breaks will be reduced to less than one in eight. A concomitant improvement in morale would be expected.

7.18 Opportunities to Test Strategies Before Implementation

Modelling and simulation described offers opportunities to test strategies before implementation. Real world implementation can be expensive, and the directors have already learned that making ‘obvious’ and ‘logical’ changes can produce counter-intuitive results. The risk of that happening can be minimised through IISD, as described: strategies can be demonstrated in a benign environment and stakeholder acceptance gauged before the potentially irreversible step of implementation is taken.

7.19 Implementation and Monitoring

The models form the benchmark for monitoring progress. Continual, and iterative, comparison between real behaviour and model behaviour is essential, as is review of subgroup and executive-level perspectives. Follow-up workshops will be needed to assess how much change in the problems situation has occurred, as far as the stakeholders are concerned. During these workshops, reference is made to the original concept maps and influence diagrams.

7.20 Pitfalls and Pointers - Student Attempts at Solving *ThreeTwoOne's* Problem

Pitfalls noted and pointers recorded during student attempts at solving *ThreeTwoOne's* problem are:

a. *Not defining each concept as a 'call for action'.* In an attempt to quickly produce a concept map, students frequently abbreviate concepts. Some forms of abbreviation are suitable: most are not. In, particular, forms of abbreviation that do not include verbs create ambiguity. For those inexperienced in mapping, the advice is simple… state the concept in full as a call for action and rely on the schema depicted at Table 7-1.

b. *Not fully testing hypotheses depicted in maps.* Each map is a set of hypotheses for the group or individual that produced the map. Before relying on any map, be it a cognitive map, concept map, causal loop diagram or influence diagram, testing of the hypotheses is needed. Care is needed that reliance is not placed on maps that have not been tested. The minimum requirement is to test that the map is logically correct and faithfully represents the views of those who developed it.

c. *Inconsistencies in depiction of direction of causality*. One subgroup might show the direction of causality reversed, compared to another group's perspective. This does not necessarily mean one group is right and one is wrong. But to minimise the chance of errors, the schema at Table 7-1 should be carefully applied. Maps of similar aspects of the same problem, but at different levels of aggregation, may show causality quite differently. For example, a nominal group working on ideas generated by a number of subgroups may interpret a problem situation somewhat differently. Again, to avoid the chance of errors, and to record rationale for a given choice, the schema at Table 7-1 should be carefully applied.

d. *Some students are not completely comfortable with concept mapping.* Whether for reasons of choice styles, explained at 7.6 above, or because

English is not their first language, some students are not comfortable with text-based concept mapping. Other forms of problem conceptualisation, such as SSM as depicted at Figure 2-9, might need to be used as alternatives.

e. *Proceeding directly to building a quantitative model*. Unless forced to proceed systematically through a conceptualisation process, one which results in the production of a qualitative conceptual model, almost every student capable of building quantitative models proceeds directly to building such models. This was found to be the case for undergraduate and postgraduate students alike. This is also common in professional practice. This last aspect will be discussed at Chapter 10. The inevitable result is incorrectly defining the problem space. The most common mistake made is to ignore or over-simplify the processing of customer orders by office staff. Such an approach ignores what turns out to be a profound influence, that of the effective manning of the office. Put simply, it is critical that somebody is available to answer incoming phone calls. Unless this is analysed through quantitative modelling, the problem is never fully appreciated.

7.21 Student Reaction to IISD and System Dynamics Modelling

The system dynamics taught at ADFA seeks to provide a conceptual basis for, and experience in, rational enquiry into and design of complex socio-technical systems. Its specific goal is to increase student effectiveness in analytical problem solving through increasing their level and use of systems thinking and system dynamics modelling. This requires that they understand problem solving as a social learning process, where the solution is an emergent property of a group enquiry. This enquiry should be based on systems thinking principles and methodologies, with particular reference to soft systems modelling and system dynamics theory. This is achieved through the application of a structured methodology (IISD) and powerful computer tools (Decision Explorer™ and Powersim™) to this realistic case study.

The UNSW undertakes periodic student ratings of all subjects. The student assessment of the Systems Dynamics subjects, at both undergraduate and postgraduate levels is very favourable in relation to student interest and perceived difficulty. On a 1-7 scale (7 being most favourable), 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, also rated the subject as more difficult than their other (more technical) units.

Follow-up questioning suggests that students had mastered the skills to address technical problems, where the objectives are clear and unambiguous. However, they were less prepared for a situation where there are multiple stakeholders and multiple or even conflicting objectives, and where the paradigm is one of mutual learning rather than optimisation. This led to a change in the conduct of the student exercise from previous years. In 2000 and 2001, more emphasis was placed on working in groups for problem conceptualisation. In these later years, the tutorial exercise was conducted as explained in this chapter.

7.22 Summary – Chapter 7

The principles of method described in Chapter 6, as drawn from the literature and empirical case studies in Chapters 3 and 4, are applied to a practical problem to demonstrate their veracity. This chapter describes step-by-step how to address real-life systemic, dynamic problems. Problem conceptualisation techniques are explained. The techniques used by a number of leading researchers were extended, based on experience gained during the conduct of this research effort and as a result of teaching systems thinking and system dynamics. Teaching and experimentation with these techniques has taken place at the Australian Technical Staff Course and the Australian Defence Force Academy over the past four years. The results of that work are explained through the tutorial itself and in a summary set of pitfalls.

7.23 Significant Contributions Made in Chapter 7

Integration of concept mapping, influence diagramming and dynamic simulation modelling in the context of a holistic problem-solving methodology, is demonstrated. The integrated methodology demonstrated provides direct, logical and traceable linkages between qualitative and quantitative analytical techniques, more so than other methods found in the literature, or known to be used in current practice.

CHAPTER 8

CASE APPLICATION - COMBAT TRAINING CENTRE WORKING GROUP

Synopsis

At 2.28, 6.27 and 7.6, it was argued that successful problem conceptualisation depends on accommodating the different views and choice styles of decision-makers. In this chapter, a group workshop was facilitated with the aims of addressing a particularly difficult problem and assisting members of a strategy development working group through the process of building a shared understanding of the problem at hand. Each person involved brought to the workshop a separate view both of the problem and what the session hoped to achieve. At the start of the session the group was told to produce a set of cogent arguments justifying the expenditure of several million dollars of taxpayers' money. The investment would result in the development of a high technology centre for building the readiness of Army company-sized groups.

Knowledge elicitation workshop techniques, similar to those described in Chapter 7 were used. A paradigm shift in the way the group members viewed the problem was produced. Whilst consensus was not achieved, differences were accommodated by the group. At the end of the process, a set of arguments justifying this capital expenditure was produced. A subsequent round of discussions, conducted over the telephone with individual group members enabled the gathering of sufficient information for the production of a Joint Issues Paper. This Paper was presented to one of the Higher Defence Committees for consideration. Whilst the Joint Issues Paper was successful in bringing a set of cogent arguments before the Committee, the priority of this Combat Training Centre project was not considered sufficiently high for funding to be allocated to it in that year. Whilst the project was deferred, the application of the techniques described is considered very successful.

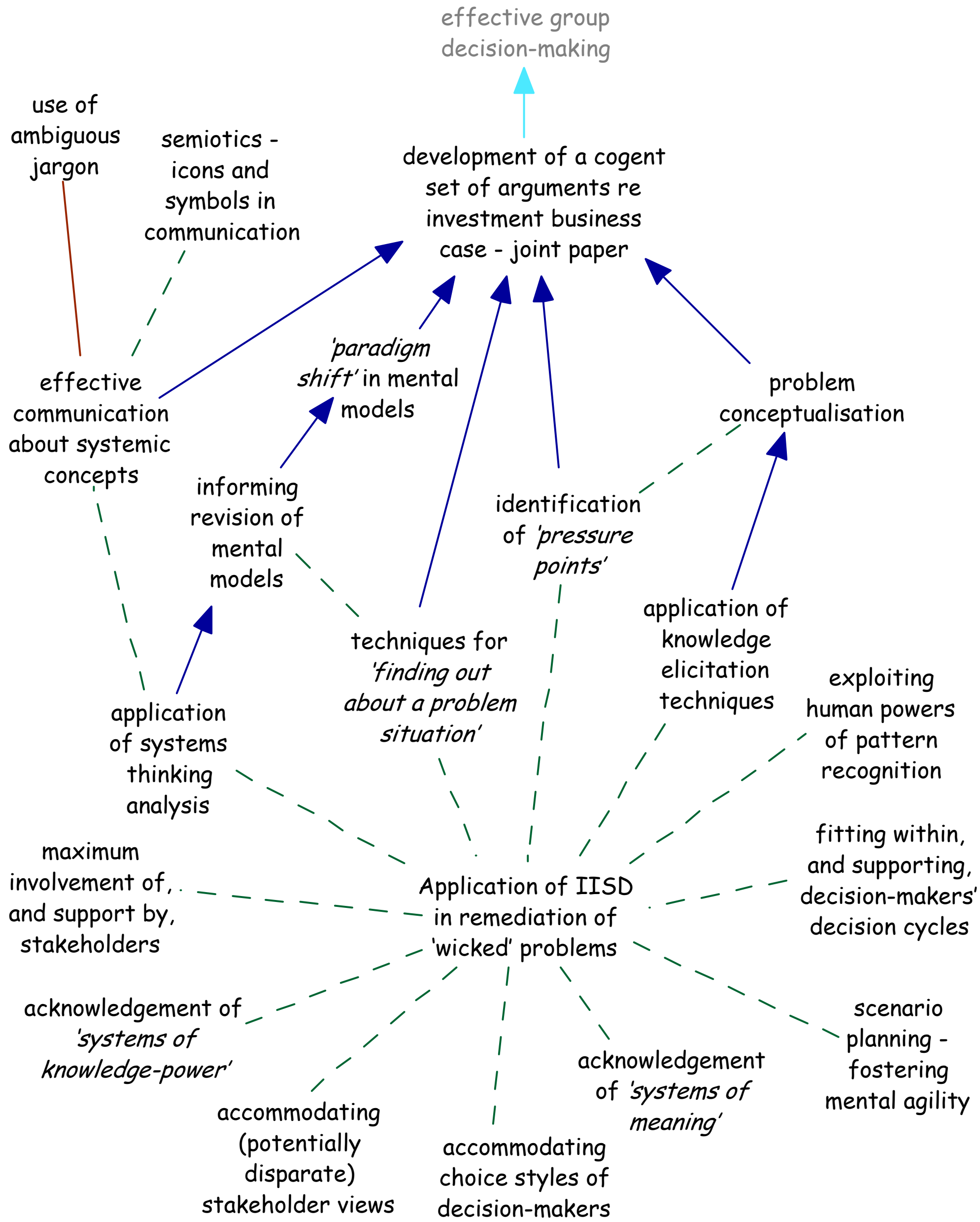


Figure 8-1. Concept Map - Chapter 8 Synopsis

<u>Note:</u>

1. Concepts shown in black text are contained in this chapter.

Recent years have witnessed increased emphasis, in systems thinking and system dynamics research, on techniques that make the task of decision-making groups easier, and enhancing the effectiveness of group decision-making. This change in emphasis acknowledges the growing importance of group decision-making. Vennix (1996) observes that the days of the solitary decision-maker have passed: more and more, the responsibility for decision-making is being given to groups.

Many practitioners are now building consultancies around techniques intended to support group decision-making activities. Too often, however, the application of such techniques is far from intuitive.

Further, there is a risk that once the consultants' report has been delivered and the consultant has left, decision-makers revert to age-old habits, appropriate or inappropriate as they may be, unless significant revision of stakeholders' mental models has occurred. Nutt (1989) is emphatic that age-old decision-making habits are very likely to be flawed, especially when they are heavily reliant on judgement and intuition rather than based on critical thinking supported by analysis.

In this chapter, knowledge elicitation and systems thinking are facilitated in a group workshop situation with the aim of producing a written Joint Issues Paper embodying a cogent set of arguments. At stake is the timely creation of a high-technology Combat Training Centre for the Australian Army.

When funding is approved, the Combat Training Centre will be build at a cost of several million dollars. The Combat Training Centre is likely to significantly improve the effectiveness of collective training and the preparedness of Australian troops.

8.1 Aims of this Case Application

The aims of this case application were:

a. By working intimately with a decision-making group, to observe how they go about analysing a real-life complex problem.

b. To facilitate group decision-making through:

   (1) systematic knowledge elicitation,

   (2) surfacing and testing of stakeholder assumptions,

   (3) fostering critical analysis of stakeholder assumptions, and

(4) application of consensus-building techniques.

c. Through a practical action research workshop situation, where a highly important problem is faced, further develop and test qualitative modelling for group decision-making and strategy development.

8.2 Task and Composition of Decision-Making Group

A working group was convened from various parts of Australian Defence Headquarters, Land Command, and Training Command for the purpose of identifying arguments relevant to the development of a Combat Training Centre for the Australian Army. The working group was tasked with producing a Joint Issues Paper on the subject of the Combat Training Centre (CTC). The paper was to identify all relevant issues such as justification, arguments for and against, and present outcomes of this workshop in a form acceptable to disparate stakeholders.

Acceptance of the Joint Issues Paper was a pre-requisite to a Higher Defence Committee meeting which would either accept or reject the CTC concept. Acceptance by this committee, the Force Structure Planning and Programming Committee (FSPPC), would lead to programming of funding for the creation of a CTC. So this was both a formative and important workshop. Each representative had different agenda, summarised as follows, based on discussions with each stakeholder before the commencement of the workshop and observations of them during the workshop:

Staff Officer Grade One Soldier Combat Systems (SO1 SCS)	SO1 SCS was tasked with acting as chairman for the working group and responsible for the preparation of a Joint Issues Paper. The intent of the Joint Issues Paper was to provide that basis for briefing the FSPPC, one of the most senior Higher Defence Committees. Being a ‘Joint’ paper meant that its content was to be agreed by stakeholders, at the SO1 level at least, before it was presented to the FSPPC.
Staff Officer ScienceLand Headquarters	To represent Land Headquarters’ interests especially in development of the capability and effectiveness of the force-in-being. He would also put forward arguments for selected technology to be used to

	improve fighting capability of Land Force soldiers, sub-units, and units.
Staff Officer Grade One Simulation, Headquarters Training Command, (SO1 Sim HQ Trg Comd)	To represent interests of Training Command in the employment of technology such as simulation to gain greatest effectiveness in individual and collective training in preparation for war.
Scientific Adviser - Army	To ensure uses of selected technology in training and preparations for war fighting were appropriate, achievable and properly balanced.
Scientific Adviser to Director General Force Development (Land) (DGFD(L))	To represent DGFD(L) on issues relating to employment of science and technology in development of Army capability and war-fighting effectiveness.
Defence Science and Technology Organisation (DSTO) representative	To represent the Chief Defence Scientist (CDS) on issues relating to the application of science and technology, to existing and future Defence capability. To ensure strategies for such application accord with CDS's long-term plans and direction.
Force Development and Analysis (FDA)	To represent interests of the Deputy Secretary Force Development and Analysis. In particular, to ensure plans and strategies would provide capability and force development in a cost-effective way.

8.3 Impediments to Identifying and Discussing Core Issues

Despite there being an agenda issued in anticipation of the workshop, as the workshop progressed it soon became obvious that those providing briefings to the group were focussing narrowly on their areas of interest and of those they were representing. There was more attention being paid to 'political point-scoring' than identifying the core issues. Speakers were not permitted by other members to fully develop arguments without interruption. The chairman had to intervene on several occasions either to limit discussion or to bring it back on track.

Formal presentations, required by the agenda:

a. tended to focus on pre-conceived ideas;

b. enunciated ideas with continual reference to process and procedure ... “the way we do it”, or “the way is must be done is ... ”; and

c. used differing language - it was obvious that each stakeholder had a different interpretation of what was meant by critical terminology central to the discussions.

Many of the terms being used were new to the Australian Defence environment and, obvious from the discussion, were being interpreted in different ways by stakeholders. Disparity over terminology and its meaning suggested the need for a glossary of terms that would provide unambiguous definition of each key term.

The aim was then to detach individuals from subject matter about which they were passionate and draw out their domain knowledge and experience in a way that would benefit the working group’s aims. The group’s main aim remained to develop cogent arguments justifying the need for the CTC. A description of CTC is at 8.4 below.

8.4 Combat Training Centre - Defined

Before the workshop, attendees were familiar with the following definition of the Combat Training Centre. The CTC is the facility in which the objective evaluation of units will be undertaken. At the most basic level, the CTC’s aim is to provide realistic collective training, using purpose-built instrumented facilities in which measurable force-on-force combat engagements can be conducted against a dedicated opposing force in the presence of dedicated control and evaluation staff.

The CTC, however, is more than a number of instrumented training areas, particularly given the introduction of mobile instrumented training systems and the development of Distributed Interactive Simulation applications. The concept is an approach to the structured evaluation and improvement of training to maximise combat capabilities. The maximisation of combat capabilities is multi-faceted, and includes:

a. force-on-force joint exercises to develop battlefield fire and manoeuvre skills and expose personnel to some of the stresses they could encounter in battle;

b. assessment and training of combat leaders in situations requiring them to provide a measurable level of collective performance from a unit;

c. ensuring that junior leaders are exposed to and are competent in a range of core skills essential to their current and future employment;

d. staff / procedural training;

e. validation and refinement of procedures and doctrine and evaluation of system performance and integration;

f. operational analysis of new systems and technology, including field testing of performance enhancements; and

g. assisting in the identification of relationship between resources expended and the achievement of a specific level of readiness.

Whilst this was sanctioned as the formal definition of a CTC, at the commencement of the workshop, there was significant disparity in levels of acceptance of this definition. This disparity extended to the purpose and outcomes expected from the workshop.

8.5 Re-Focussing Group Attention

As there was disparity about the direction the working group should be heading, and about concepts and goals, the attention of the group was drawn to a set of six questions proposed by the author of this dissertation. Each member was asked to write down, in dot-point form, answers to each question, keeping them private until asked to contribute to group discussion. They were instructed not to dwell overly on their answers as there were no right or wrong answers, and no penalties for making mistakes.

8.6 Seed Questions Posed to the Group

Seed questions posed to the group to provoke thought and to direct the dialogue were:

Q1. What are the primary reasons for collective training in the Army?

Q2. What is the Army trying to achieve now through collective training rather than what it ought to be achieving for the future?

Q3. What are current constraints on the way Army conducts collective training.

Q4. What do you see as the future constraints on the conduct of collective training? Is prospect worse or better in the future?

Q5. What are the main risks to developing how we will undertake future individual and collective training?

Q6. What are the key capability deficiencies Army is trying to address through Army in the 21st century (A21)/Restructuring the Army (RTA) initiatives?

The questions were intended to prompt thinking about a number of central themes that could be further developed through group discussions.

After having noted their answers, members were asked to consider the causal relationships, rather than process linkages, between any of the factors they had noted by using a logical linkage of the type ‘leads to ... ’, such as is expressed in the statement ‘smoking leads to heart disease’ as explained at Chapter 1.

It was carefully explained that cause-and-effect relationships were important as were feedback mechanisms. Four of the group were scientists with postgraduate qualifications. The remaining three were tertiary qualified but not in science or engineering. It was not difficult to elicit a meaningful definition of feedback acceptable to the group. Although initial discussion avoided the notion of feedback, after a period of discussion about apparently disparate ideas, the group realised that these ideas were actually linked in a series of feedback loops.

The group used the diagram Inputs / Dev / Training / Ops to build on the concept of feedback. Figure 8-2 was expanded to show feedback from lessons learnt and feedback from the doctrine development process.

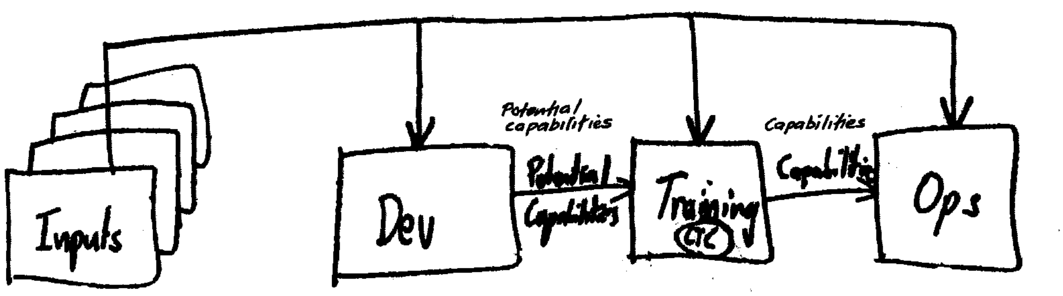


Figure 8-2. Initial View of Inputs / Development / Training / Operations

Notes:

1. Where necessary, unreadable details have been augmented by the author of this dissertation.

The result of is at Figure 8-3.

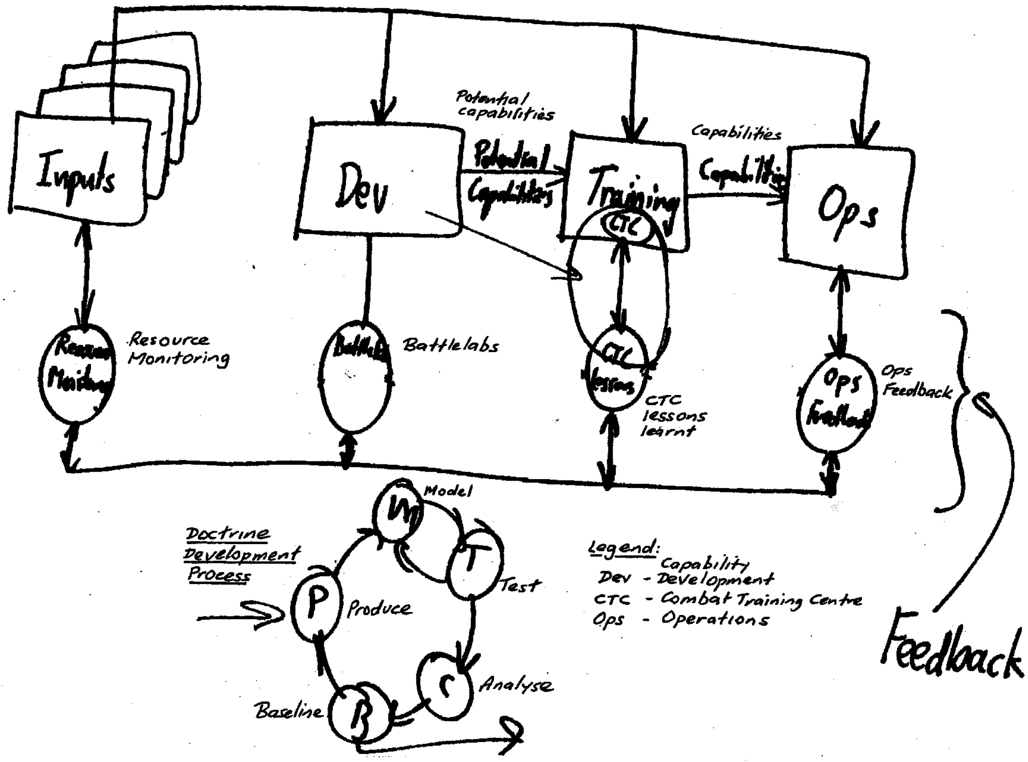


Figure 8-3 Enhanced View Showing Central Role of CTC and Various Feedbacks

At this point the attention of the group was re-directed back to the six questions asked. The group was asked to complete their answers without reference to their neighbours or other discussion.

8.7 Analysing Responses

The whole group addressed each question in turn. Members were asked to contribute through incremental building of a set of concept maps. They were asked to add concepts, draw connecting arrows and explain the cause and effect logic behind each arrow.

Concept Diagrams are shown in Figures 8-4 – 8-9.

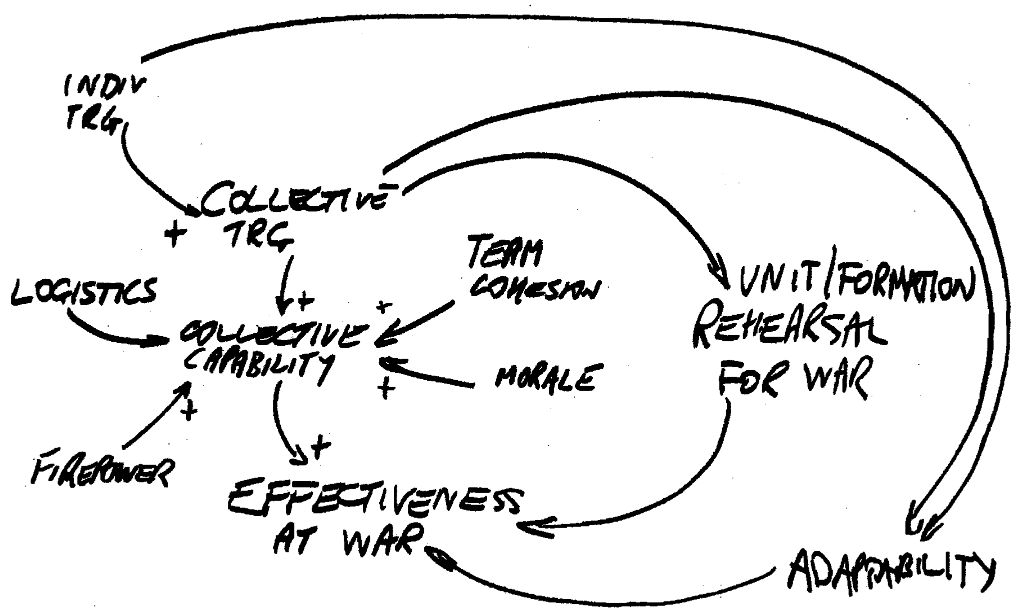


Figure 8-4 Concept Map Elicited in Response to Question 1

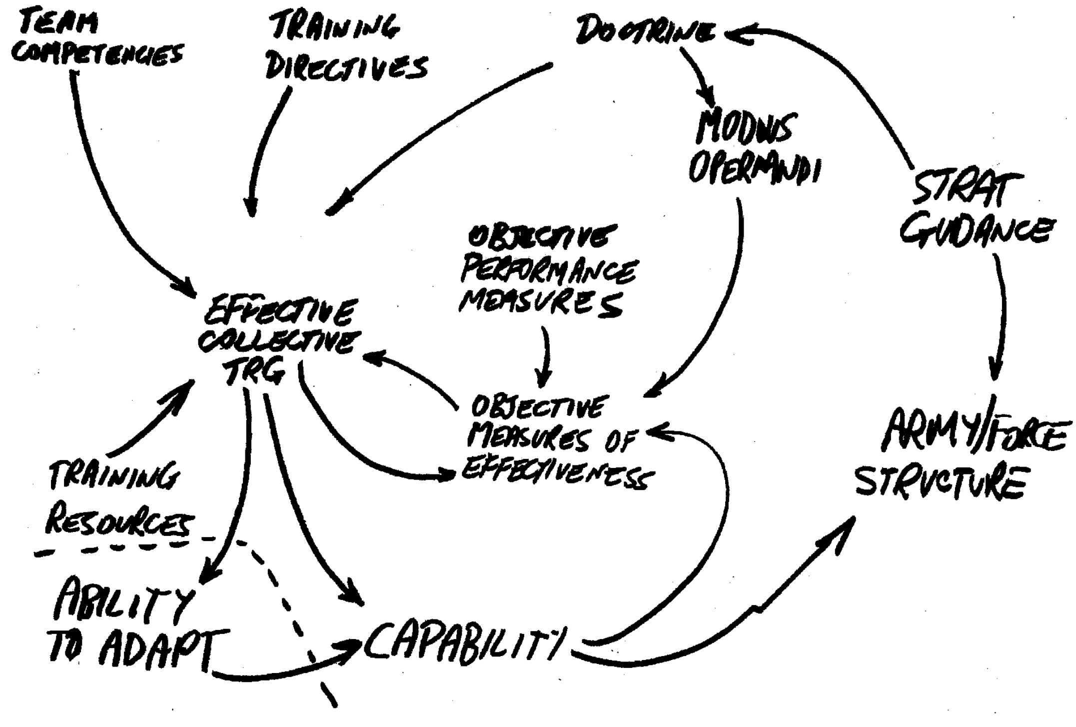


Figure 8-5. Concept Map Elicited in Response to Question 2 (1)

<u>Notes:</u>

1. Bi-directional arrows were interpreted as connotative links. Further explanation of bi-directional arrows is at 11.13.

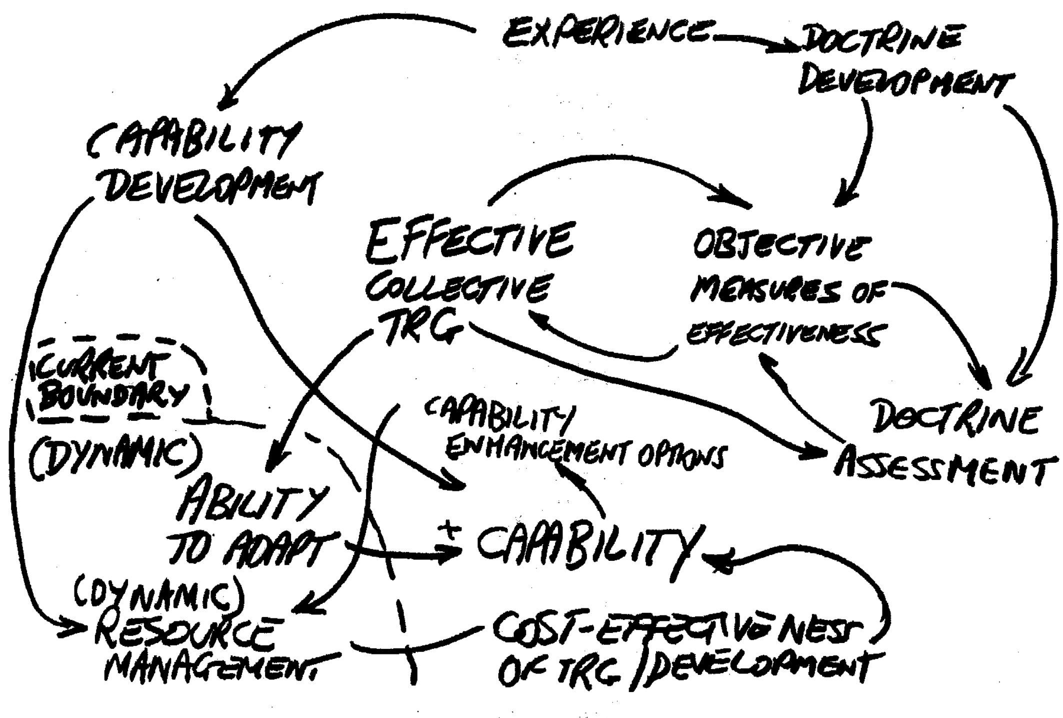


Figure 8-6 Concept Map Elicited in Response to Question 3

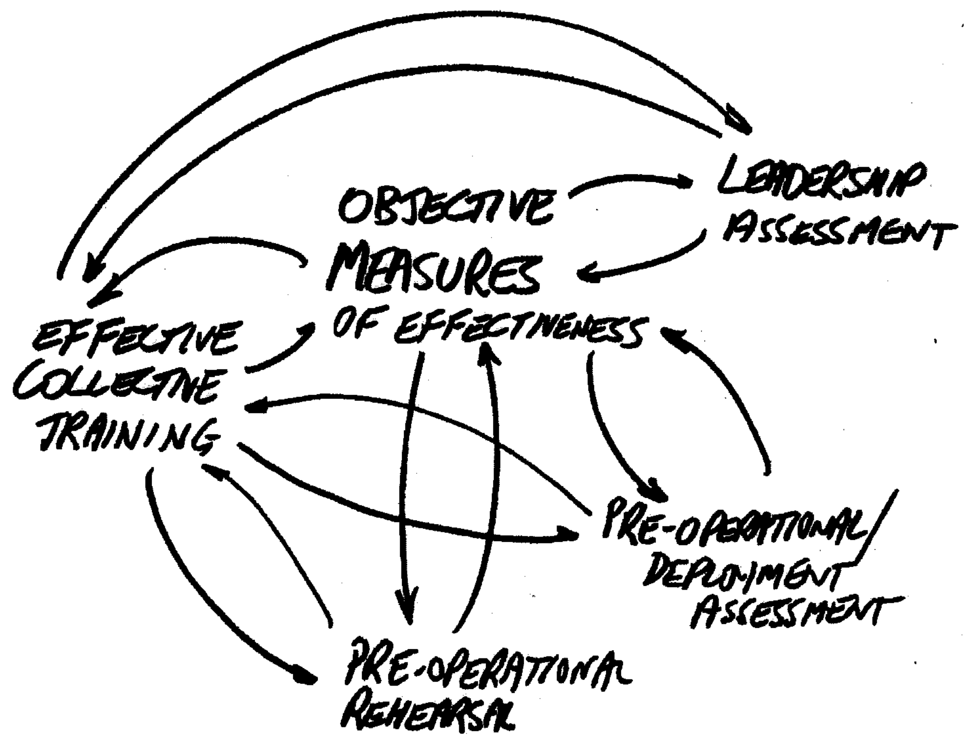


Figure 8-7 Concept Map Elicited in Response to Question 4

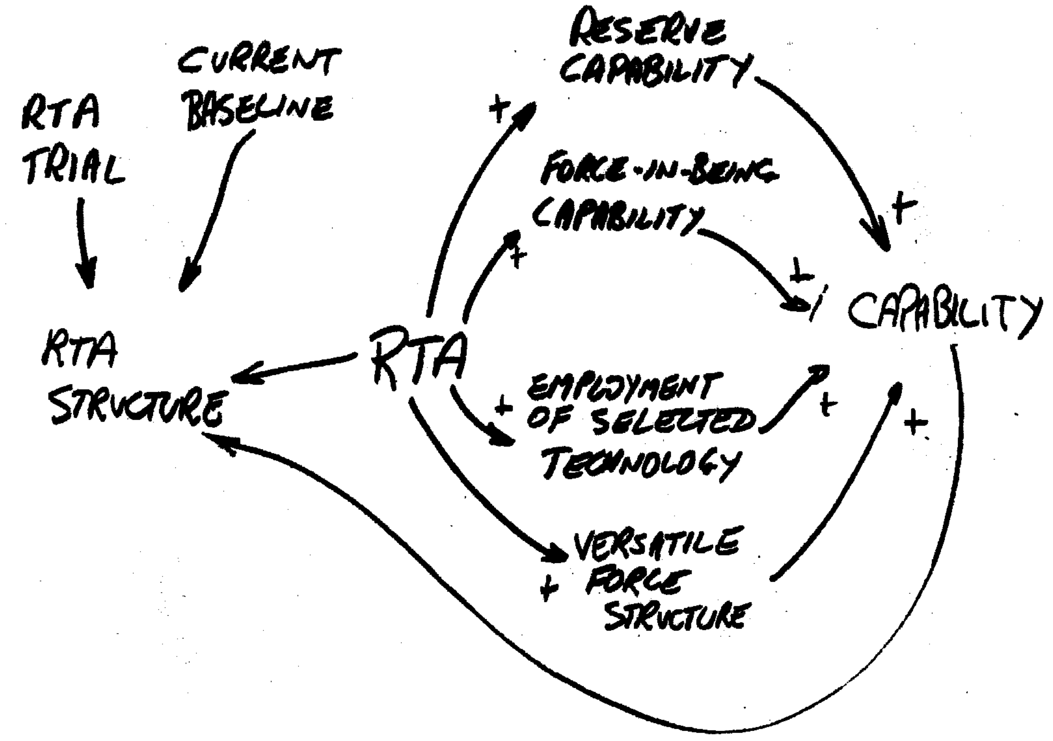


Figure 8-8 Concept Map Elicited in Response to Question 5

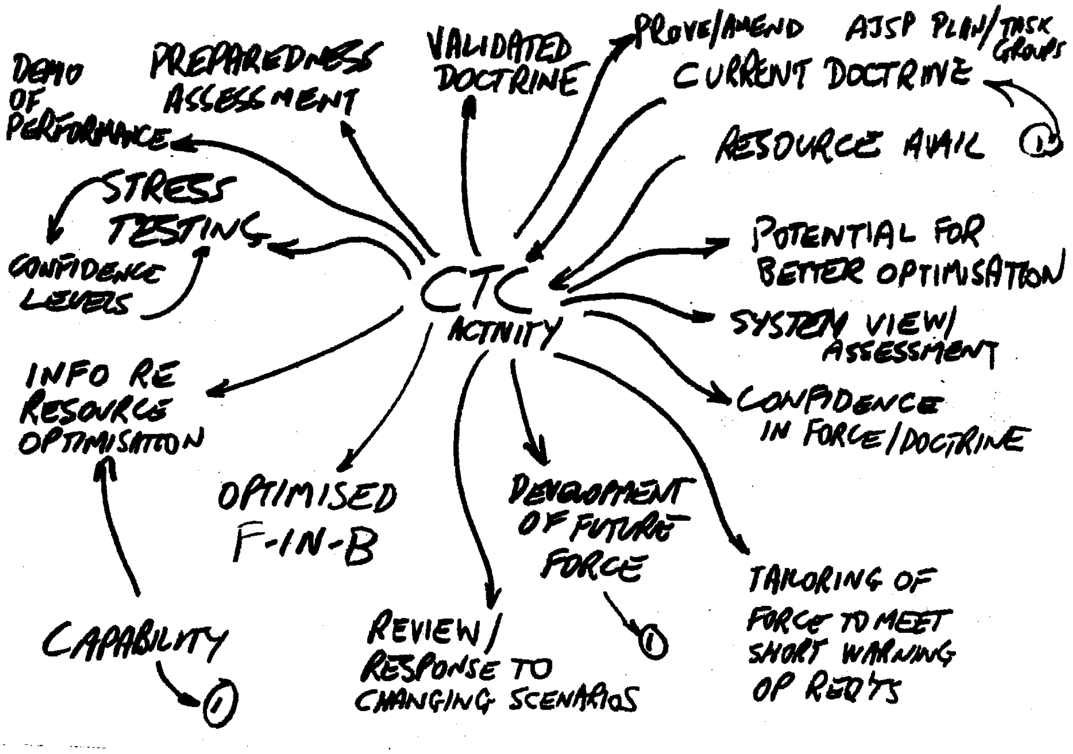


Figure 8-9 Concept Map Elicited in Response to Question 6

8.8 Working Toward a Shared Understanding

As the diagrams grew they were continually reviewed to ensure they reflected a group perspective as far as possible. The questions were used to prompt thought and galvanise members into active discussion rather than produce a specific answer. From time-to-time, there was animated discussion about the meaning of a particular concept description or causal arrow, including direction of causality. Diagrams were criticised, re-drawn, explained, summarised and amended until general agreement was reached. At no stage was completely unanimous agreement reached. Where strong views were held, individual members were asked to explain their reasoning until a compromise, or at least accommodation of disparate views, was reached. This was reflected in the diagram using the language agreed to by the members involved in the discussion.

In turn, each member was asked if they felt sufficiently comfortable to accept the diagram as:

a. representing their own view, and

b. providing a group view with which they had no significant disagreement.

Each diagram was printed. Use of an electronic whiteboard with a photocopying facility proved most valuable. Each member was given a full set of photocopies and a continued process of review, with free and constructive criticism encouraged. Often there were debates along the lines “ ... you didn’t say that earlier ... that isn’t in the diagram ... please explain that last point ... ”. Through this iterative review process an agreed set of concept diagrams were produced. These were again photocopied and handed to group members.

Before the workshop concluded, members were asked to lay each of the diagrams out so a holistic view could be taken. They were asked to identify linkages between the diagrams. Several additional arrows were added. It was agreed that the diagrams were all part of one large map which still had some pieces missing.

8.9 Reflecting Upon Achievements

The chairman summarised achievements of the workshop and follow-up tasks. It was agreed:

a. The concept maps produced would form the kernel of arguments to be incorporated into the Joint Issues Paper.

b. Individuals would supplement the maps with additional concepts after they had returned to their respective offices.

c. The Draft Joint Issues Paper would be circulated for comment by the specified date.

A printed set of diagrams was produced within two days and faxed to members in-lieu of minutes.

8.10 A Further Iteration Conducted by Telephone Polling

During a follow-up telephone poll, each member expressed satisfaction with the approach taken, especially with how intuitive it was. The whole process of knowledge elicitation, production of group maps and completion of the telephone poll took around a week, mainly because each of the stakeholders were concurrently managing a range of tasks.

8.11 Recommended Way of Conducting Elicitation Workshops

The recommended approach would be to conduct this over two consecutive days. The first workshop could be completed in less than half a day, including familiarisation training on systems thinking, concept mapping and group decision-making. The second workshop, including validation of the maps by members of the group could be completed in around an hour.

8.12 Development of the Joint Issues Paper

Concept diagrams were used to inform development of the Joint Issues Paper. The achieved level of acceptance of this paper was high because agreement was achieved through the following processes in a non-threatening environment created by the facilitator:

a. knowledge elicitation,

b. dialogue,

c. assumption surfacing, and

d. concept mapping and analysis.

The whole process was completed whilst it remained fresh in the minds of the group members.

In order to permit analysis of these diagrams, a series of Decision Explorer® concept maps were produced. These are shown in Figures 8-10 to 8-11:

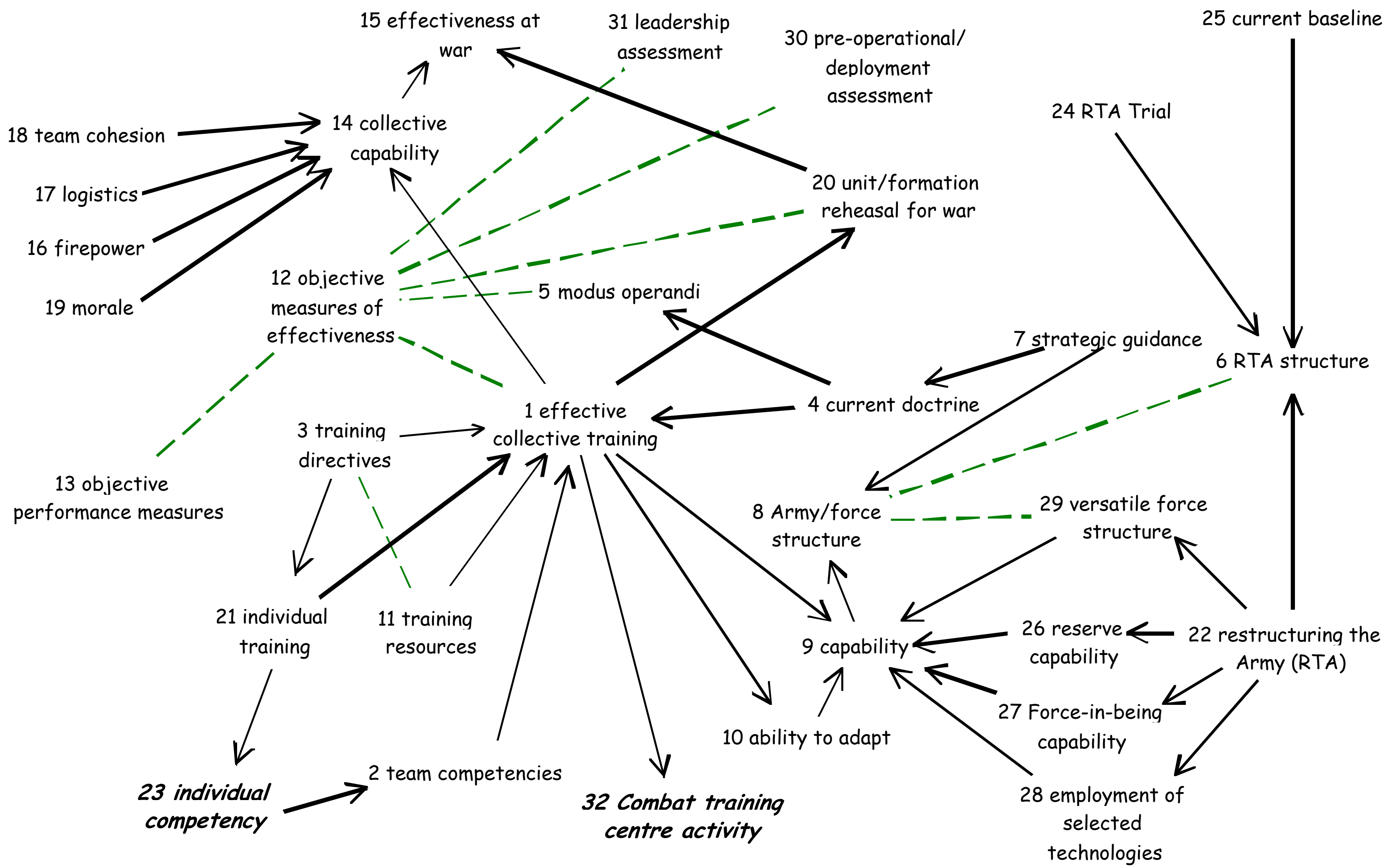


Figure 8-10 Central Focus on Concept *1. effective collective training* – Depicts an Interim Stage of Building a Complete Map

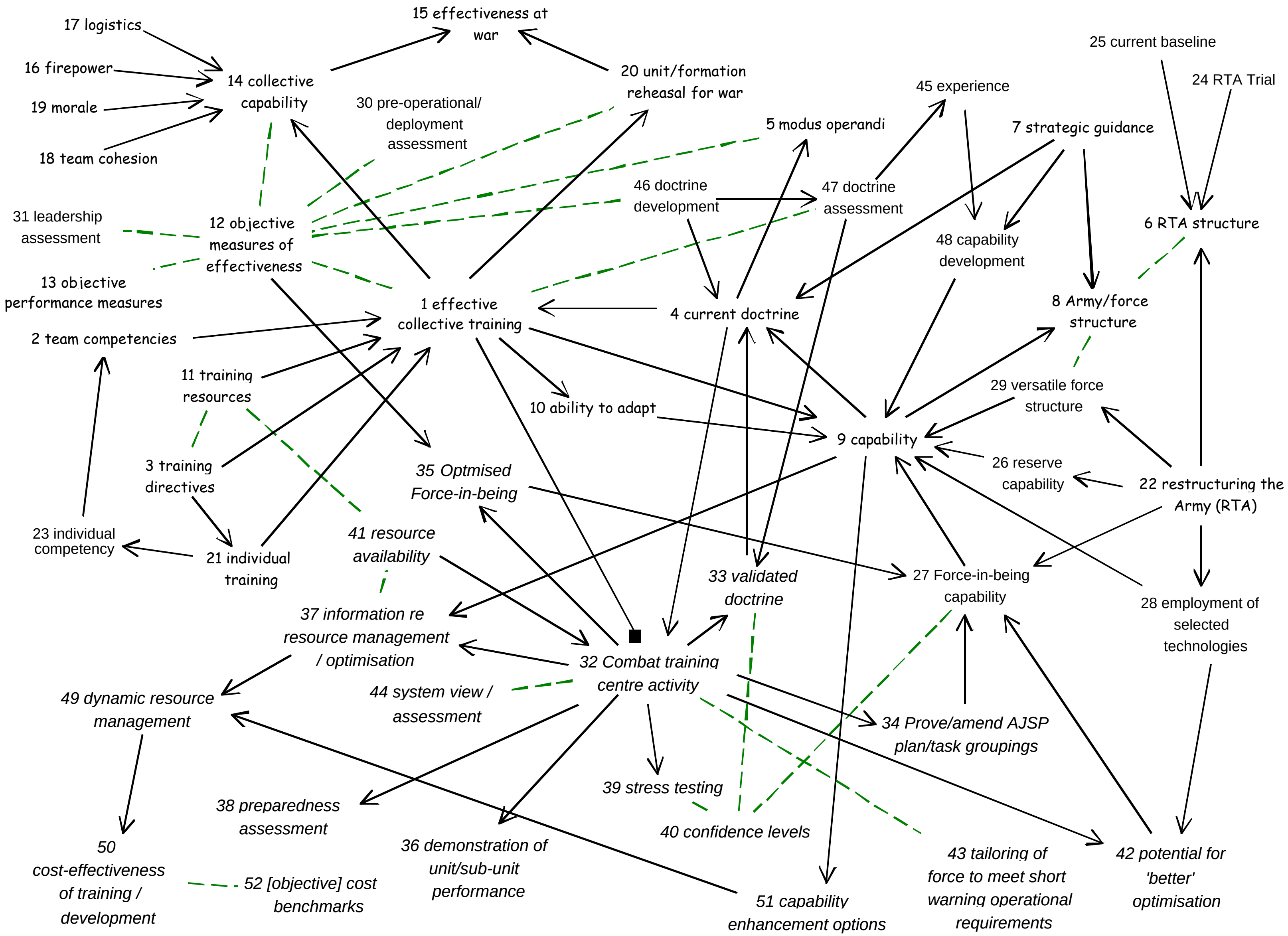


Figure 8-11 All Concepts Enunciated by the Working Group

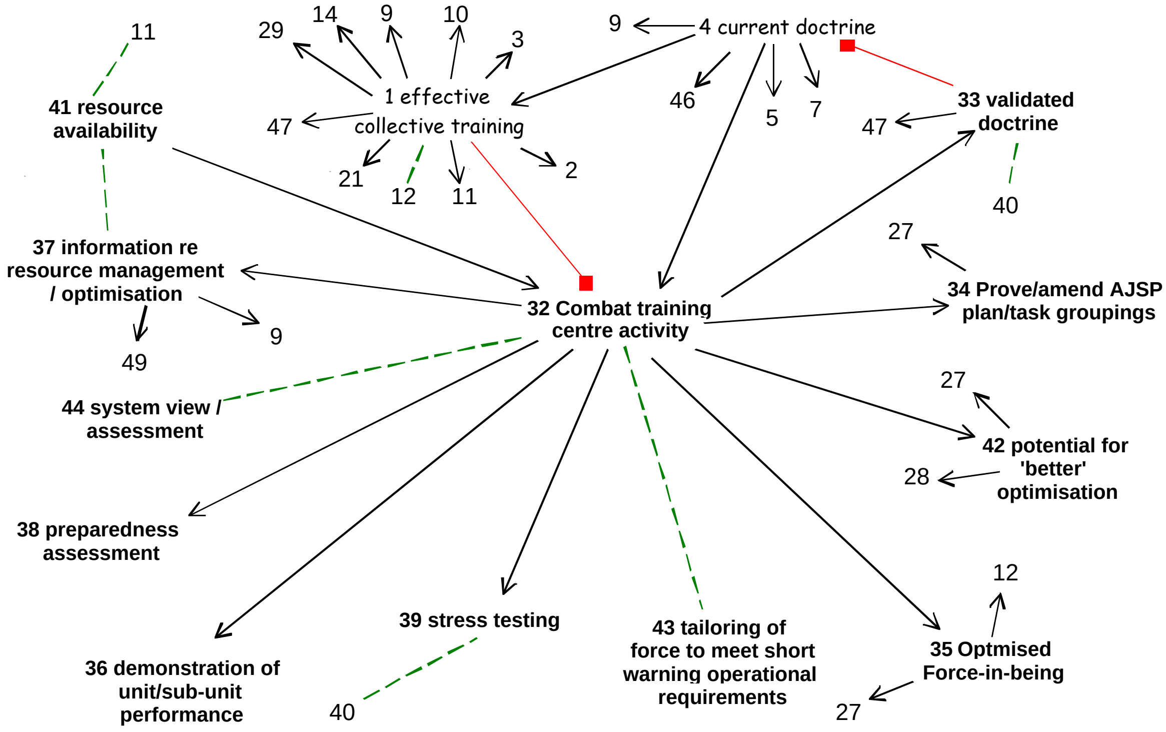


Figure 8-12 All Concepts Related to Concept *32. combat training centre activity*

8.13 Observations from Workshop Activity

This mapping technique:

a. provided a progressive record and audit trail of the knowledge elicitation process it can be very useful to backtrack to review how arguments developed;

b. logged individual assumptions and facilitated the surfacing of other such assumptions and 'hidden agenda';

c. graphically depicts all relevant concepts and interrelationships between them;

d. permits detailed analysis, such as:

(1) identification of most influential nodes by simply counting the number of related concepts or the number of arrows connected to the concept under examination;

(2) focussing on the kernel of concepts related to one key concept; and

(3) identification of feedback structures involving, for example:

(a) doctrine-related concepts 4, 1, 12, 46, 33, 45, 48, and 9; and

(b) capability-related concepts 9, 4, 1, 10, 37, 48, 29, 26, 27, 51, and 37.

e. assists in identification of logical omissions or errors, for example concept *23 individual competency* was added for logical completeness (note that a detailed analysis of logical completeness was not part of this study since the main aim was to aid the group in developing concepts and arguments for inclusion in the Joint Issues Paper);

f. assists in identification of aspects worthy of closer scrutiny, for example, concept *50 cost effectiveness of training / development* should be linked back to the defence budget, which in turn should be linked to funding available for capability development and preparedness - issues of critical concern for FASFDA.

8.14 Incorporation of Mapped Details into the Joint Issues Paper

The ‘Joint Issues Paper on the Combat Training Centre’, an extract of which is included as Figure 8-13 in the following two pages, show where relevant concepts have been incorporated.

Figure 8-13 Extract from Draft Issues Paper (Annotated)

(See following two pages)

Systems Development (Battle Lab)

15. The first step in the Systems Optimisation Process is the development of a workable system and modified methods of operation that can enhance the performance of the combat soldier and combat units. A Battle Lab process is evolving from Project WUNDURRA, involving a strong and structured research, testing and feedback capability to support the development of the SCS. Systems development will also be supported by objective evaluation in a CTC.

Systems Training

15 14 18 17 16 19 35 16. Once a system has been developed, the combat soldier must receive comprehensive and ongoing training in its use. The aim of this training is to ensure that the performance of combat soldiers and units is optimised and that integration into the greater battlefield system is achieved. Systems-based training, as opposed to training in individual items of equipment, will become increasingly important with increased levels of technology and the spread of C^3IS linkages across the battlefield.

Objective Evaluation

21 1 12 13 31 14 15 17. The final element of the SOR is the formal objective evaluation of individual and collective training. Training evaluation is concerned with measuring the effectiveness and efficiency of training, ensuring that lessons are captured and providing formal feedback into systems development and training processes. The application of an objective evaluation process by means of the CTC concept has the potential to be one of the most significant methods of enhancing the performance of the Land Force.

Research Results

18. The related Capability Analysis for Project WUNDURRA has reinforced the capability deficiencies identified earlier in this paper, by highlighting that the lack of a SOR in Army imposes the following limitations:

14 1 15 12 13 a. Systems optimisation will be difficult for both the SCS and greater battlefield systems if the interaction of all these systems is not rigorously developed and tested.

14 15 12 5 4 8 51 9 50 b. Objective evaluation of collective performance cannot be achieved resulting in difficulty measuring baseline performance and the effects of technological, doctrinal and structural enhancements.

c. Endorsed concepts, such as continuous improvement for both individuals and units, are difficult to implement without accurate performance data.

12 13 1

19. The analysis identifies the CTC as a vital component of the SOR, particularly supporting the requirement for a capability to measure performance conduct training in a controlled or free play environment, and test altered organisations, doctrine, technology and logistics. The Joint Issues Paper on Project WUNDURRA of 6 Nov 96 recommended consideration of a Combat Training Centre (CTC) as part of a SOR. Following adoption of the regime for Project WUNDURRA, it is **recommended** that the CTC be accepted as the part of that regime able to provide a capability for objective evaluation of training.

USER REQUIREMENT FOR OBJECTIVE EVALUATION OF TRAINING

Army Collective Training Capability

20. The Army Training System (ATS 94) requires all training to progress from individual training to teamwork, then to collective training. Underlying the concept of the training model is continuous evaluation, ensuring that training is progressive and objective. It involves the five steps of design, development, conduct, validation and analysis of collective training, with review occurring continuously. To be effective, the process needs to be conducted objectively, but currently the Army has only a limited ability to objectively analyse, evaluate and validate collective training.

21 23 2 1 12 13 14 15

12 13 31

21. The Development Plan for Training (FRAC 7), prepared by DGFD(L), identifies the lack of tools for the empirical measurement of training effectiveness and efficiency as 'a significant deficiency in training'.[12] In addition it notes the requirement to ensure that 'mechanisms for validation, updating and dissemination of doctrine development complement technology improvements within Army'. Currently, except for major exercises, Commanders are responsible for collective training, and plan, conduct and self evaluate their training activities. Evaluation is generally subjective, based upon the perceptions of Commanders, umpires and exercise opposing force (OPFOR). Post-activity reports with lessons learnt may be promulgated within a formation or unit, but generally are not disseminated on a wider basis. This deficiency could be addressed by providing a training facility for objective evaluation as the culmination of the training cycle for all operational formations and units, to assist commanders to assess the readiness level of their units.

[12] DGFD(L) FRAC 7 of Jun 95.

8.15 Responses Regarding the IISD Process

Even those group members initially most reluctant became very supportive of the IISD process and accepted the final maps as a valid and cogent basis for developing the Joint Issues Paper. The Joint Issues Paper was used to inform the FSPPC deliberations. The CTC Project had insufficient priority to be granted approval, in this its first year of consideration, but the arguments identified formed the basis for subsequent justification. Details of the CTC Project are classified and so complete details cannot be included here. An extract from the original Joint Issues Paper is at Figure 8-13.

8.16 Case Study Findings

This case study showed:

a. how simple, yet powerful, techniques assist in focussing group members' attention onto critical issues and systemic structures;

b. the need for systems thinking in group decision-making; and

c. how concept mapping can facilitate the surfacing of assumptions and building of consensus.

d. even for a group containing predominantly PhD scientists, who should be very familiar with the notions of feedback and dynamic behaviour, there can be significant initial reluctance to discussing concepts using systems thinking terminology and taking a holistic view;

e. concept mapping can be very effective in depicting complex interrelationships in such a way that:

    (1) encourages dialogue;

    (2) depicts important causal, connotative and conflict relationships; and

    (3) aids in the development of cogent arguments.

f. concept map agreed by the group in a workshop environment is preferred to any consolidated map that might be produced off-line by an analyst.

Concept mapping is but one technique for finding out about a problem situation. Here it is used simply as an example of the process, its strengths and weaknesses. The analyst's toolbox should contain a range of tools and techniques to aid knowledge elicitation and critical systems thinking. These can be selected and applied according to client preferences for information presentation and processing (Churchman, 1971), as explained at 6.27.

8.17 Summary Chapter 8

In this chapter, IISD was applied in a limited way to a group decision-making task. Disparate stakeholders were brought together with a remit to produce a cogent set of arguments regarding a relatively poorly defined, but highly important problem. Potentially, investment of several million dollars could result from the group's deliberations. Initially, the group were using jargon and language that confused the issues and approached the problem from their own particular viewpoints, with little consideration of building a shared understanding of why they had been brought together. At first, they could not agree the scope of the task. Applying IISD principles of method helped overcome the impasse that had developed among stakeholders. Alignment of ideas came about through establishing effective communication about systemic concepts: after early disagreements, the group recognised that they were facing a moderately complex, and highly systemic, problem. It also became clear that identifying the systemic structure and 'pressure points' within that structure were the group's main tasks. It also became clear to the group that the extent to which arguments they might present in the Joint Issues Paper were cogent, would lead to acceptance of the Paper by the Committee. The group's attention changed to identifying where money should be invested to gain best effect, that is, the 'pressure points' of interest to the Committee. This application of IISD, albeit a limited one, is considered highly succcessful.

8.18 Significant Contributions Made in Chapter 8

This chapter has demonstrated the disparity of thinking amongst members of a team ostensibly working together to produce a declared outcome. It was also demonstrated how different ways of thinking are accommodated through workshops, which employ IISD to create a shared understanding through the building of qualitative models of a complex problem situation. The qualitative model became the summary of a set of hypotheses, which were tested and subsequently incorporated into a Joint Issues Paper, which was presented to, and considered by, one of the most powerful Defence Higher Committees. Demonstrating the progression from qualitative models summarised as concept maps to textual form is important given the reliance, in Chapters 3 and 4, on written reports to create concept maps. That is, the reverse of the process demonstrated in this chapter. This chapter serves to further reinforce the legitimate linkage between knowledge elicitation and qualitative modelling.

CHAPTER 9

IISD CASE APPLICATIONS: FROM BUSINESS PROCESS RE-ENGINEERING TO RELIABILITY PREDICTION

"[Successful] strategic innovation is more likely to occur in an organization when its members are able to articulate the mental models which shape key decisions as well as the deeper beliefs and core assumptions underlying both thinking and action (Bennett and Brown, 1995: 168)."

Synopsis

This chapter describes how IISD was applied, albeit in a limited way, to re-engineering of the business processes of the Australian Defence Acquisition Organisation (DAO). By the time this case application commenced, the consulting arm of the IBM Corporation had already been contracted by DAO to design the Business Process Re-engineering (BPR) intervention. IISD was used to provide independent verification and validation of the design of the intervention in respect of Performance Reporting and Evaluation (PR&E) for major capital acquisition projects.

Concept mapping techniques were used to support interviews with senior executives, members of the BPR team, and other important stakeholders. Information gathered enabled analysis of the need for, and risks associated with, re-engineering of PR&E processes. One particular PR&E aspect, that of reporting Cost Variance (CV) and Schedule Variance (SV) against the project baseline of major capital acquisition projects, was identified as carrying high risk. The methods used in practice by DAO to gather and analyse CV and SV information were investigated. A system dynamics simulation model was built as a tool to demonstrate how variable delays in collating and processing PR&E information could lead to an erroneous view of project progress. A second case application presented in this chapter demonstrates the application of IISD to a problem of predicting the reliability of a satellite communications network so that an appropriate logistic support strategy could be devised.

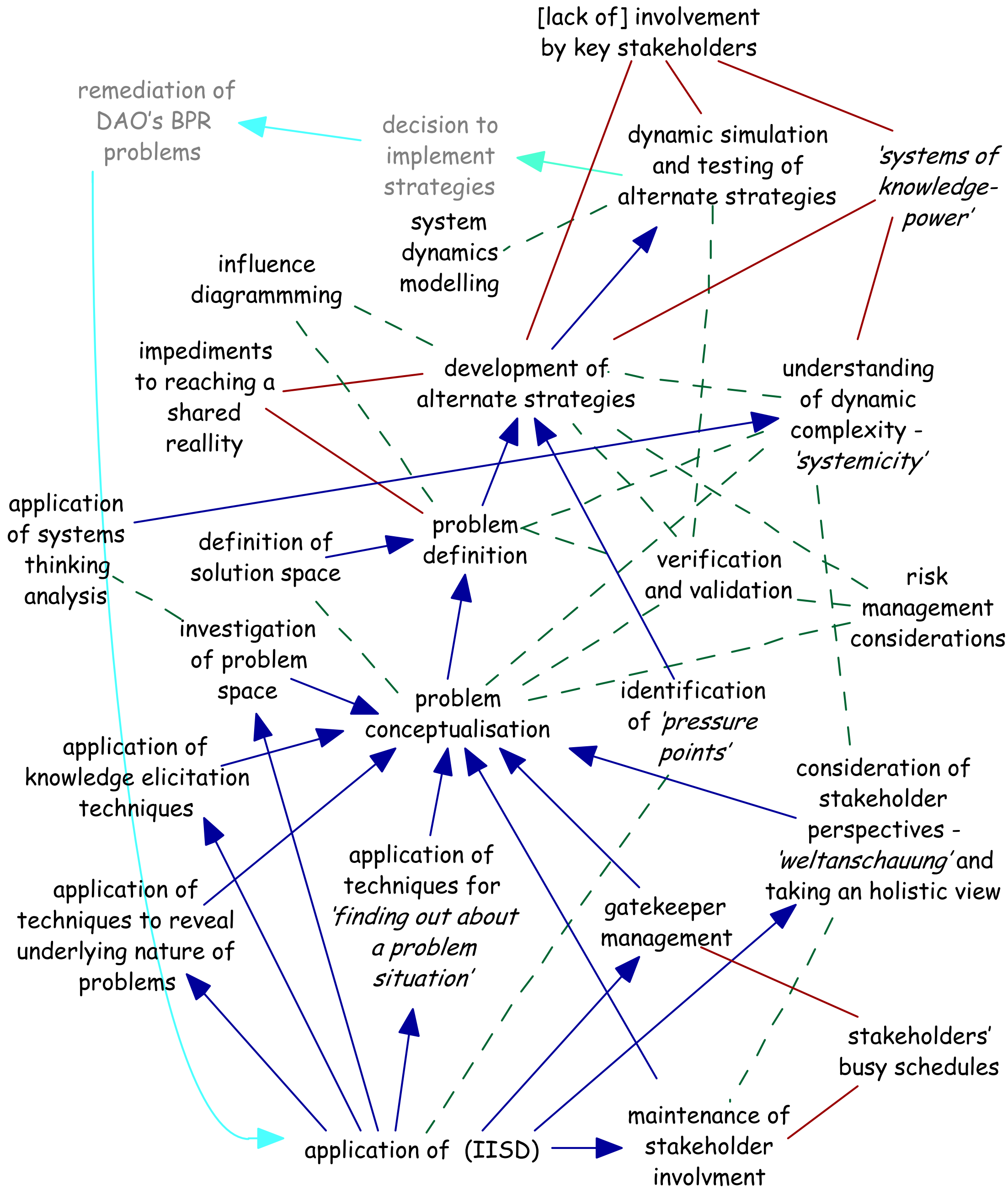


Figure 9-1. Concept Map – Chapter 9 – Synopsis

Note:

1. Concepts shown in black text are contained in this chapter.

On 10 March 1997, the recommendations of the Defence Efficiency Review (DER) were made public with the release of the DER Report. The Canberra Times newspaper published the estimated cuts in Defence Acquisition as $37 million annually, starting with a ‘one-off’ cut in the size of the organisation by 356 personnel. Late in 1997, Business Process Re-engineering (BPR) of Defence Acquisition practices commenced with the aim of producing the cuts required by the Government.

The need for BPR had been foreshadowed in the DER recommendations and was to be conducted as part of the Defence Reform Program (DRP). BPR of the Defence Acquisition Organisation (DAO) was undertaken in one of the early DRP implementation phases. The main BPR activity was to take the form of a review of the efficacy of management of capital acquisition projects. These projects consume a large portion of the AUD $10 billion annual Defence budget. At any point in time, DAO is committed to, is in the process of planning, or is executing some AUD $6 billion in capital acquisition projects.

On 1 July 1999, the Minister for Defence formally made public the ‘Report on the Collins Class Submarine and Related Matters’. This was released under cover of a media statement entitled ‘Reform of Defence Acquisition’ which stated, *inter alia*:

> … at the last election the Government promised “the Defence procurement process will be made more flexible, responsive, innovative and efficient”. [But the Report on the acquisition of Collins class submarines reveals]… the management structures and contract arrangements established at the beginning of the project have been inadequate to provide the necessary oversight to ensure the project could be successfully concluded within an acceptable timeframe… I am today announcing that the Government has decided to [again] restructure the management of the Defence procurement organisation...

It again became clear that the BPR initiative, commenced in 1997, did not produce reforms of the DAO, its management, and its processes to the extent expected. The efficiency and effectiveness dividends the Government had hoped for had not materialised. The question is: why?

In 2001, many major capital acquisition projects are still under the spotlight for continued cost and schedule over-runs and under-achievement of technical performance. Another review of the DAO, recently re-titled Defence Materiel Organisation (DMO), now threatens a further cut of some 500 personnel in a major reorganisation. These cuts are being accompanied by yet another overhaul of acquisition management practices.

This case application of IISD commenced in March 1998 and continued for four months and focused on the early stages of the first of recent reorganisations of DAO. This chapter shows that the DAO business processes, which were being re-engineered, were complex. They were more complex and more strongly coupled than many appreciated. Also the thinking of those with stake-holdings in the acquisition processes was very resistant to change. This resistance was seriously under-estimated both by those who mandated the BPR activity, and those who managed the design of the BPR intervention.

9.1 Business Process Re-engineering of Defence Acquisition

The research activity started with a series of interviews with Dr Ron McLaren, Director General Acquisition Management Systems. He explained the aim of the BPR organisational change intervention was to enhance the ability of DAO to meet its mission. The main factors to be taken into account in the execution of BPR, and anticipated outcomes were summarised in a presentation which he gave to the Defence Logistics Conference in March 1998, a couple of weeks prior to this initial meeting. The full details of the DGAMS presentation are contained in the enclosed CD-ROM. A concept map was prepared on the basis of the presentation. The presentation had been provided by Acquisition Management Systems (AMS) staff as part of a briefing pack. During the first interview, the scope of the BPR initiative and the relationship of the proposed research with that initiative, were discussed.

9.2 A Revised View of the Importance of Performance Reporting and Evaluation

During the first of the interviews with DGAMS, the IISD methodology was explained. This prompted general discussion about the structure of complex problems, which then led to specific discussions about the scope of BPR and the way it would be conducted.

Given the focus of this research activity was to consider the relationship between Performance Reporting and Evaluation (PR&E) and BPR, it started to become clear that objective measures of the efficacy of BPR would be needed. Otherwise, like the Black Hawk case and numerous cases in the systems thinking and system dynamics literature, recurring problems would remain unsolved, and systemic errors would continue unchecked. That is, if improvements were actually being made this should be measurable against a set of objective measures. That observation led to a suggestion of greater emphasis on measuring performance both of the organisation, and the BPR intervention itself.

As a result of this discussion, it was agreed that DGAMS' presentation to the Logistics Conference did not address these performance measurement aspects sufficiently, and that the current view of the problem was deficient in two specific areas:

a. Overall measures of performance for DAO, in respect of meeting that organisation's mission; and

b. Objective measures against which anticipated improvements in efficiency, effectiveness, quality, and technical performance might be gauged.

As a result of the interview, Concepts 15 and 17 were added to the concept map at Figure 9-2. Note that when the map was drafted, numbers were not used to identify individual concepts. The numbers have since been added. The pervasive way Concepts 17 and 15 are linked to many other concepts in the map, was viewed initially by DGAMS and some members of his staff with some surprise. As the significance of each link was critically examined, the realisation grew that these concepts and their linkages were vital both to PR&E and the BPR activity, overall.

9.3 Validation – A Critical Step in the Development of the Concept Map

Every concept map contains a series of hypotheses about a problem situation perceived by an individual, or group member. In this instance the map, Figure 9-2, depicted how DAO would set about improving its processes, at least from the point of view of DGAMS. Because DGAMS had overall responsibility for the conduct of the BPR organisational change intervention, this map also contains a number of important implicit assumptions about the conduct of that intervention, and how those aims would be achieved.

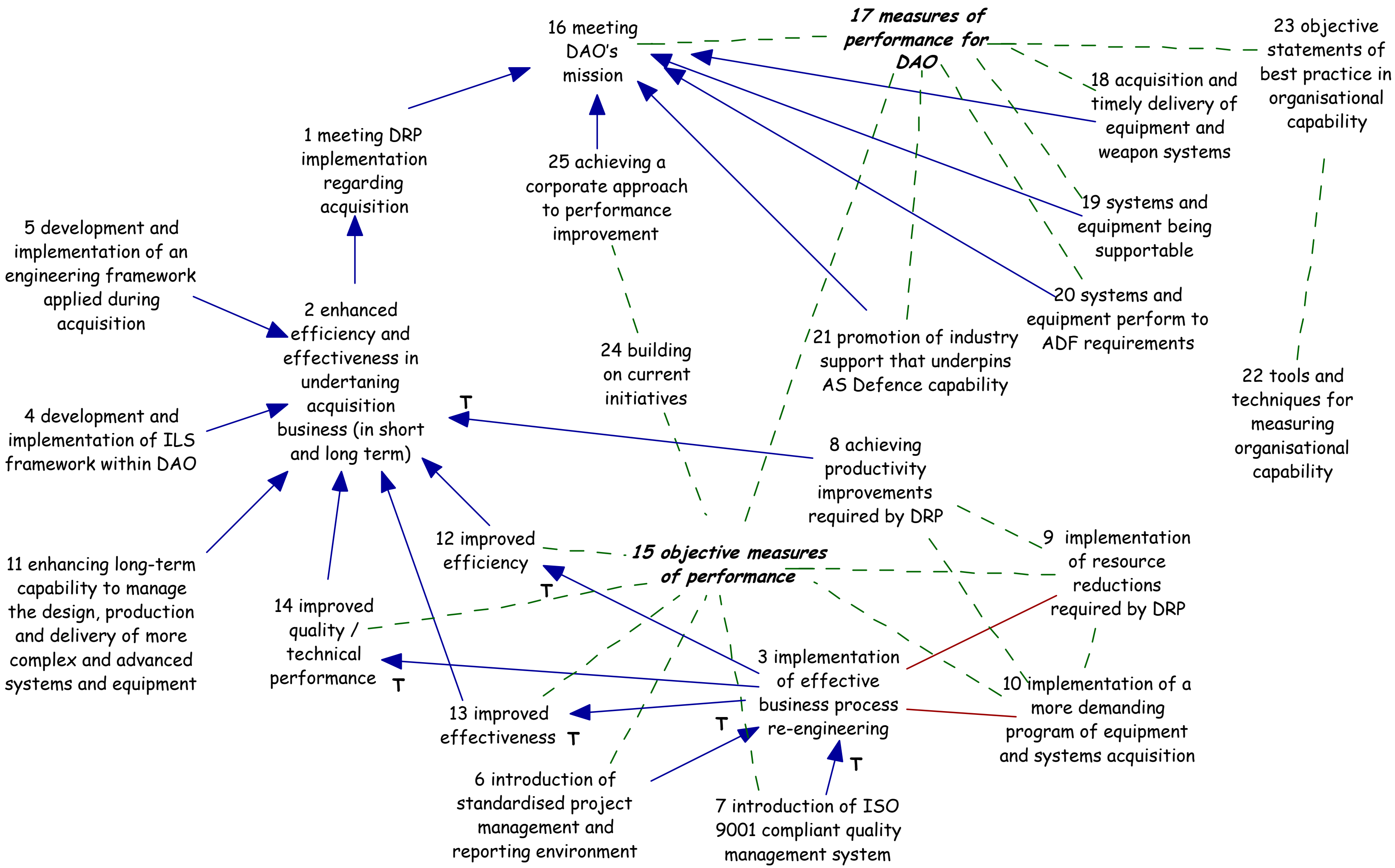


Figure 9-2. Enhancements Hoped to Flow from DAO Business Process Re-engineering

It is essential to validate concept maps with the originators of the ideas depicted in those maps. Validation of maps, which record the views of a group, was discussed at 7.10. In instances where information about a problem situation is elicited during one-on-one interviews, at a follow-up meeting the interviewee is briefed on the concepts and linkages depicted in the map, then given an opportunity to critically examine every concept and every link recorded. Step-by-step, this establishes whether, or not, the map is a faithful record of interview. If errors in recordation are found, the map must be corrected before proceeding. This process was followed throughout for each of the one-to-one interviews.

Without formal and accurate recording of hypotheses about a problem situation, subsequent testing of relevance and validity of such hypotheses would not be possible. Creation and testing of hypotheses, and adjustment of schemata, or mental models, are activities fundamental both to the learning process and to action research. Further, without such validation, it would be difficult to justify the research approach described in this dissertation as one based on the application of the scientific method.

The revised map, Figure 9-2, was validated during a subsequent meeting with DGAMS. At the end of this meeting, DGAMS agreed that the map faithfully recorded the content of the presentation, as modified by the interview process and subsequent discussion. A copy of the map was left for DGAMS to retain for future reference.

9.4 Scope of Interviews and Discussions

The main means of eliciting knowledge was through a process of interviews with key stakeholders. Interviews proved to be most practical because of the seniority of stakeholders involved, that they were very busy. In the course of the PR&E research activity, the method most frequently involved the following sequence of events:

a. *Identification of stakeholders to be interviewed.* Sponsor of this case application and modelling gatekeeper, DGAMS was consulted regarding who could be interviewed. Selection of interviewees was based primarily upon their knowledge of Defence acquisition business and their likely post-BPR roles. DGAMS stipulated that interviews were only to be conducted after he had been consulted.

b. *Gaining approval to interview the stakeholder.* Once approval in principle was obtained, the intended interviewee was contacted by telephone, or electronic mail, by the PR&E team leader. The purpose was to arrange the interview and agree its scope. Generally, discussion and questioning was initially limited to set questions. All interviewees permitted follow-on questions, but the time for questioning was generally limited to 10-15 minutes.

c. *Conduct of interviews.* Interviews took two forms. The first form was one-on-one, such as those with DGAMS described above, whilst the second form was a highly structured interview led by the PR&E team leader, and attended by PR&E team members and myself. In this case the PR&E team leader directed the questioning.

d. *Analysis of concept maps.* In the case of one-on-one interviews, concept maps were validated jointly with involvement of interviewees. This took place during a subsequent interview, as described at 9.3. In the case of PR&E team interviews, the team joined in analysis of the maps produced during the interviews. In a way, this was a surrogate form of action research, but one which involved the PR&E team as a nominal group, rather than the key stakeholders. Analysis took the form of discussions aimed at testing the veracity of hypotheses recorded in the maps. Frequently consensus was achieved, but there was often disagreement at this stage.

e. *Reflection upon Findings.* During this activity, the content and relevance of the interviews were reviewed and reflected upon in the context of the whole PR&E task. The risks to the PR&E task were generally discussed. For example, this subsequently led to the decision to look more closely at one particular project. See 9.17.

f. *Design of next stage of BPR intervention*. During this activity, discussions focused on what was to be done during the next stage of the intervention.

9.5 Practical Difficulties in Conducting This Research Activity

A number of practical difficulties were encountered in the conduct of this research activity. On many occasions, a disturbing lack of shared understanding of what might be achieved as a result of re-engineering Defence acquisition, and how the changes would be achieved, were observed. Morale was low because jobs were increasingly under threat. Many employees were more concerned about their future than they were of developing a better appreciation of how to build a more efficient acquisition organisation, and how to achieve highly effective acquisition processes.

Some members of AMS staff placed barriers in the way of IISD action research. Barriers included deliberately constraining questioning of interviewees and limiting access to information. Access to stakeholders was sometimes denied apparently on the basis of potential, or perceived, hostility to the BPR organisational change intervention.

9.6 Departure from the Preferred Procedure for Validating Concept Maps

Departure from the normal validation procedure became necessary because:

a. Generally, it was not possible to have a follow-up interview with high-profile key stakeholders. Their busy schedules made follow-up interviews difficult to co-ordinate, even with full support from DGAMS.

b. The PR&E team leader carefully controlled the conduct of interviews. Indeed, by imposing close controls, he effectively limited opportunities to follow the IISD action research methodology. This situation arose despite initial assurances, by DGAMS, that IISD-based research activity would be given full support. The staff involved saw action research having aims contrary to the rather ruthless imperative of BPR, and was seen as running contrary to what was being done under contract by the IBM Corporation.

c. Whilst DGAMS was the *modelling gatekeeper*, PR&E team leader was a true *gatekeeper* in that he actually controlled access and the availability of information. The *gatekeepe*r role, see 7.4, carries a somewhat sinister connotation when the ‘knowledge-power’ that the PR&E team leader exercised, is considered. For an explanation of ‘systems of knowledge-power’, see 2.26.

So, the default validation scheme, employed for other than one-to-one interviews, involved detailed discussions amongst the PR&E team members who had attended the relevant interviews. The team were able to confirm what had been discussed, and what the interviewee’s responses had been. Given the circumstances, this was a practical way of ‘fleshing out’ the maps, but it had significant limitations in respect of action research and action learning.

9.7 A Cardinal Rule of IISD Broken – Action Learning Opportunities Lost

Following the default (modified) validation process, described at 9.6, had the consequence that the assumptions and mental models of the key stakeholders could not be interrogated directly, except during the initial interview. Unfortunately the causal linkages between concepts could not be fully validated according to the schema at Table 7-2.

The important inputs that were missed were the valuable 'Comments' that would have given greater insight into what the interviewees were really thinking. Consequently, the extent to which mental models and assumptions held by the stakeholders could be revealed was limited by:

a. the duration of a single interview;

b. the ability of the person leading the interview to ask the 'right' questions, that is, incisive questions that were formulated on the basis of a thorough understanding of the problem to be addressed;

c. the extent of follow-on questioning permitted by the interviewee; and

d. the points of clarification, and expansions, offered by the interviewee at the time of interview.

Adjustment of the mental models held by the key stakeholders would not occur as a direct result of the process described in 9.6. A cardinal rule of IISD had been broken, that of continually and intimately involving the key stakeholders. Action learning amongst the PR&E team was a likely outcome, but this would not be an outcome shared by the key stakeholders.

9.8 Stakeholders Interviewed

The following stakeholders were interviewed:

a. Acting First Assistant Secretary Capital Equipment Procurement, Mr Gil Watters.

b. Head Systems Acquisition (Maritime Systems), Rear Admiral Peter Purcell.

c. Head Systems Acquisition (Electronic Systems), Mr Jim Noble.

d. Head Systems Acquisition (Aerospace), Air Commodore Ray Conroy.

e. Director Acquisition Management Systems, Mr Peter Hallams.

f. Director Project Management Information Systems Project, Mr John Whitacker.

g. Director Project Management Systems, Mr Jim Muir.

h. Assistant Director Project Management Systems, Mr Jeff Clark.

i. PR&E Team Leader, Mr Joe Coyle.

j. PR&E Team Member, Mr David Evered.

k. PR&E Team Consultant, BPR Methodology, Mr David Leaney (IBM).

l. PR&E Team Member, PRINCE2®, Mr Ray Broadbent.

m. PR&E Team Member, Quality Systems, Mr Manfred Holston.

n. Project Management Senior Lecturer, ADFA, Mr Alan White.

o. Project Management Systems Staff Member, Mr Mark Gairey.

p. PR&E Stakeholder's Group Member, Colonel Geoff Barnett.

q. PR&E Stakeholder's Group Member, Mr Mike Harrison.

r. PR&E Stakeholder's Group Member, Lieutenant Colonel Mike Phelps.

Records of Conversation / Interview were prepared. In those cases where time was limited, or concept maps were sketched out primarily as transient objects to enable discussion, formal transcripts were not prepared. However, records in the form of concept maps were retained. See 9.8.

9.9 Summary Concept Maps Produced

The following concept maps were produced as summaries of the interviews, reviewed in consultation with the PR&E team working in the role of a nominal group, in an adaptation of the procedures described at 7.7 – 7.10:

a. Figure 9-3 – Senior Management Involvement.

b. Figure 9-4 – Integrated Logistic Support Framework.

c. Figure 9-5 – Engineering Framework.

d. Figure 9-6 – Performance Reporting and Evaluation Framework.

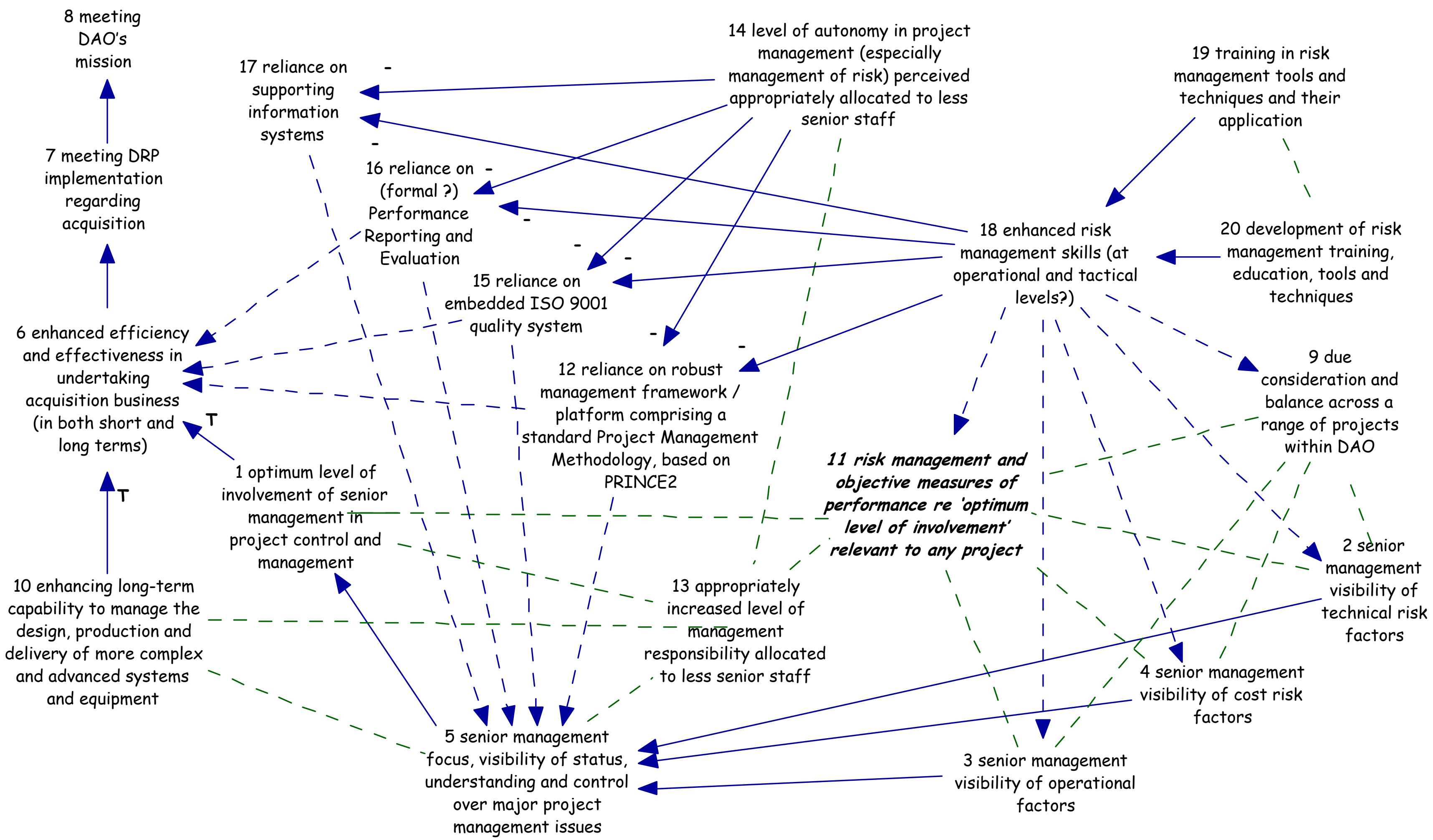


Figure 9-3 – Senior Management Involvement

9.11 Logical Omissions Identified

As in Figure 9-2, in Figure 9-3, various logical omissions in the content of interviews were identified. These were corrected by the addition of:

a. Concepts in bold italics.

b. Causal, connotative and conflicting links to, and from, the newly added concepts.

c. Causal links, shown with dashed rather than solid lines.

Only when these changes were made and each link validated, through discussion amongst members of the nominal group, did the logic of the maps appear complete. It also became clear that some causal linkages had not been given much thought. For example, in Figure 9-3, it was seemingly assumed that by relying on information provided by information systems (Concept 17), such as Project Management Information System (ProMIS), which it was assumed would provide the necessary and valid information, senior managers would have visibility of progress being made (Concept 5). Further, the post-BPR project management framework would afford greater levels of responsibility to less senior staff (Concept 13), it was hoped. In turn, this and a combination of senior management visibility (Concept 5), were expected to lead to some ‘optimum’ level of involvement of senior management (Concept 1). Even at this level of aggregation, it is clear that a number of dubious arguments were being developed about how to enhance the efficiency and effectiveness of undertaking acquisition business (Concept 6).

There was a commonly expressed assertion that by making an organisational or process change, improvements in effectiveness and efficiency would naturally follow. These assertions were untested, and the basis for making those assertions was unclear. At the time of writing the final version of this thesis, May 2001, the Head of the Business Information Systems Division (HBIS), within the newly reorganised DMO, Air Vice Marshal Col Hingston, was reviewing mechanisms for reporting the performance in project management, and the supporting information systems. During an interview with HBIS it was again clear that those responsible for managing Defence acquisition are confronted by an organisation, process and procedure (and organisational politics), that are highly complex, systemic and dynamic. With hindsight, it is clear that those involved in the PR&E activity did not have the tools and techniques to analyse the complex, dynamic systemic business processes they were trying to re-engineer.

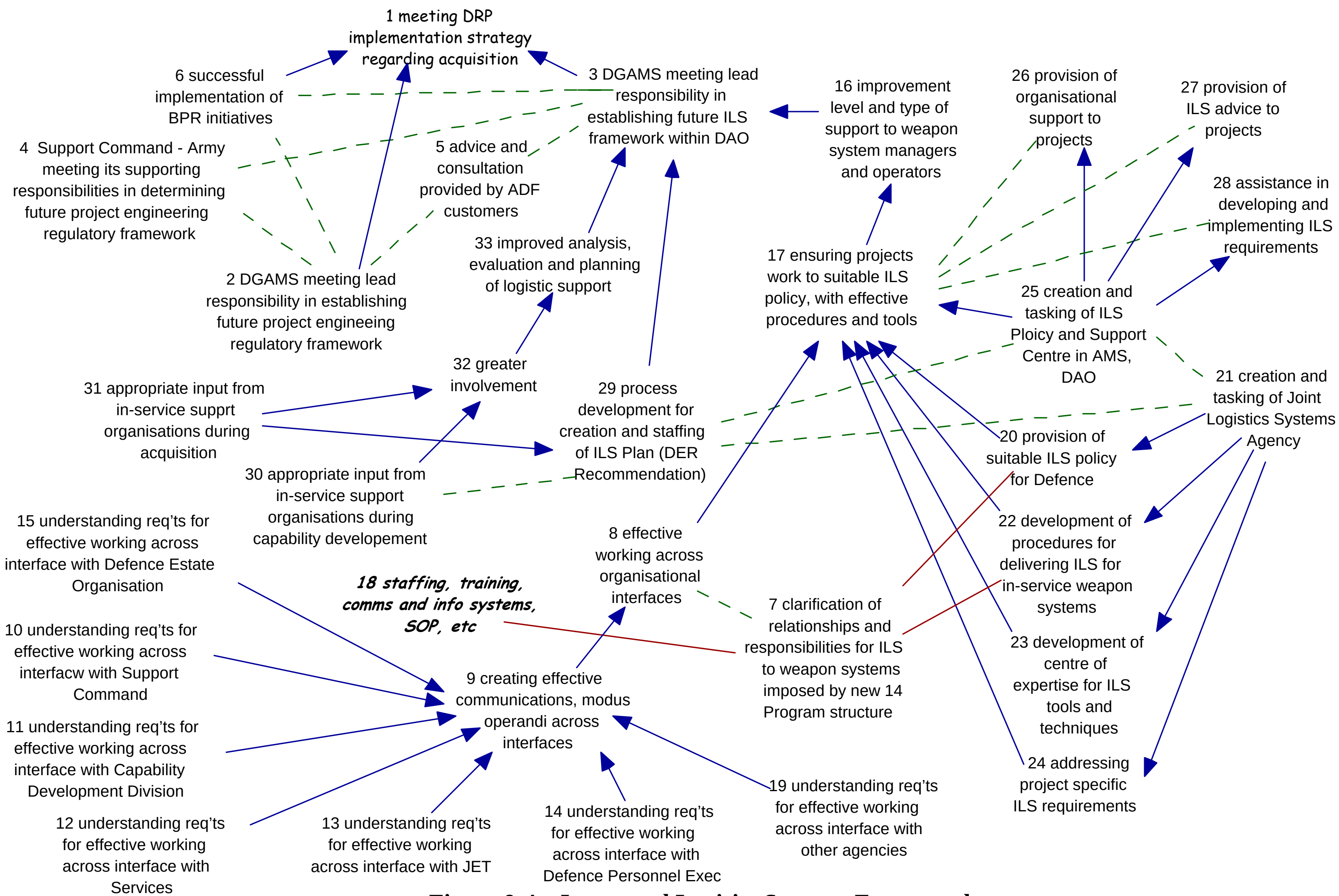


Figure 9-4 – Integrated Logisitc Support Framework

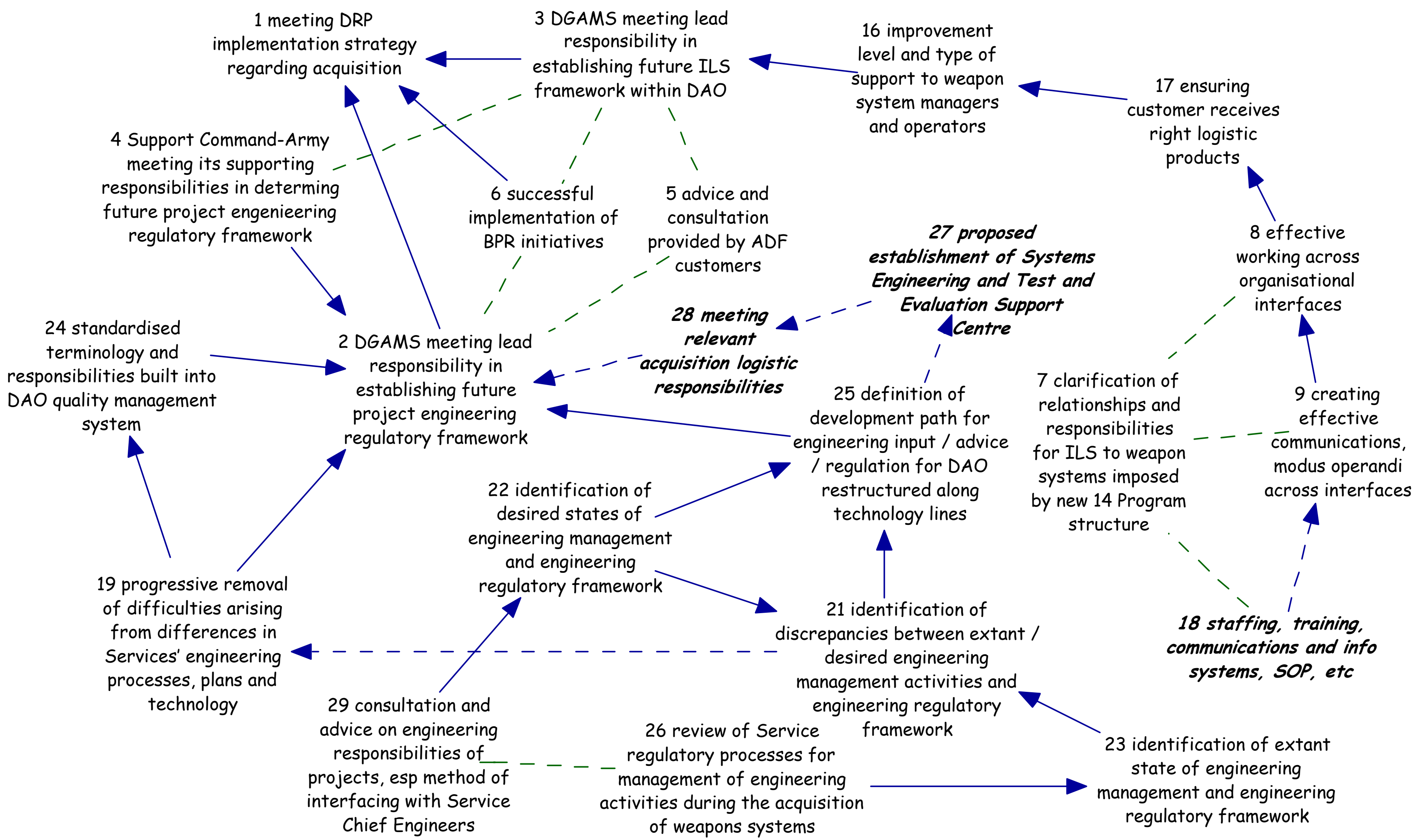


Figure 9-5 Ğ Engineering Framework

9.14 Key Performance Indicators for Measuring Progress and Project Performance

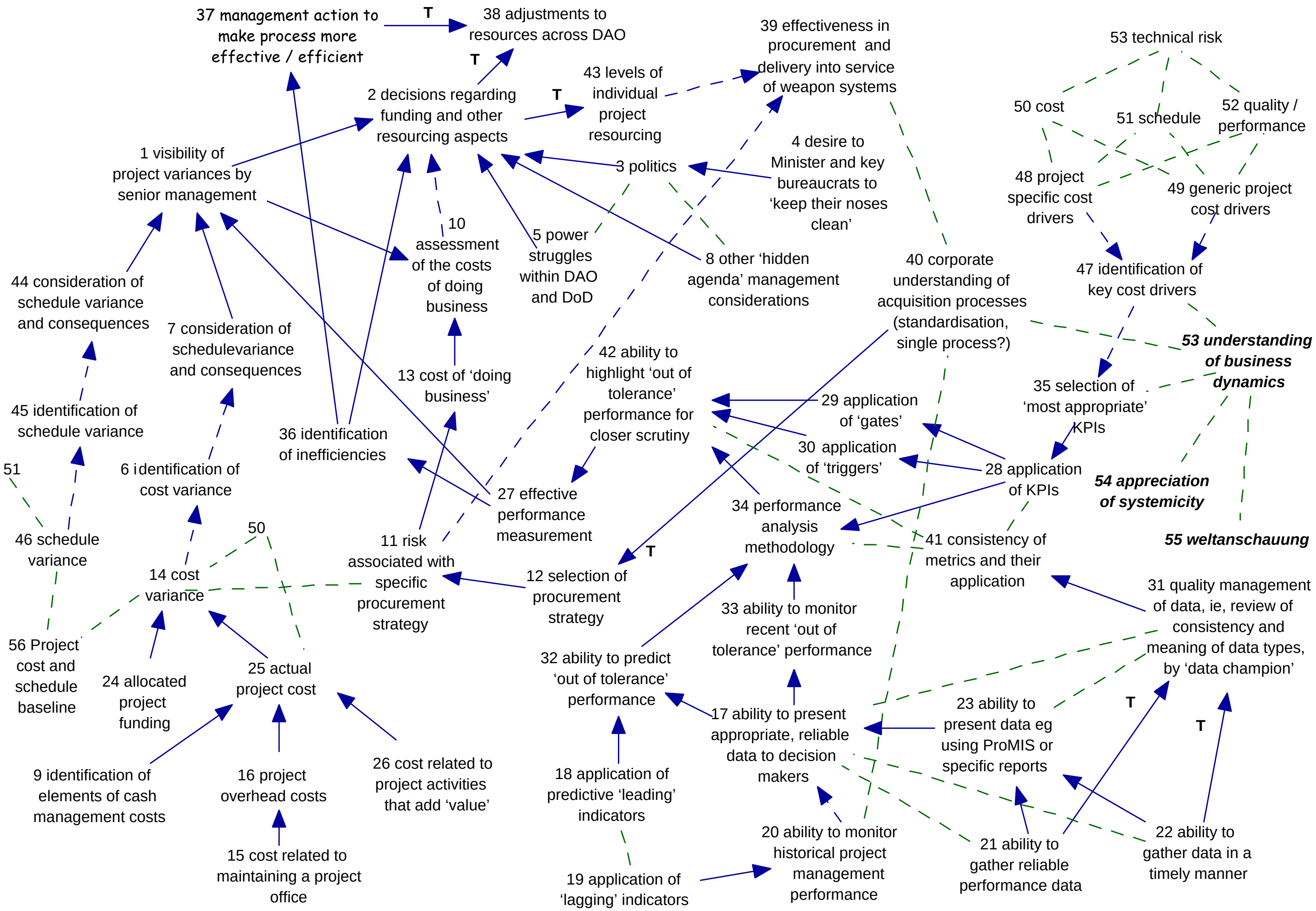


Figure 9-6 – Performance Reporting and Evaluation Framework

As stakeholders were progressively interviewed, the picture of the interrelationships between PR&E concepts became more complete. That picture, in the form of a concept map is at Figure 9-6, above. This map was the product of interviews of those stakeholders listed at 9.7, and extensive discussions involving members of the PR&E team. The PR&E team served as a nominal group, and their ideas were used to transform maps, sketched out earlier during the conduct of stakeholder interviews, to form a summary view.

9.15 Reification of Concept Maps Using Nominal Group Technique

The risks in any process of reification, noted by Eden and Ackermann (1998b: 193), are acknowledged. But, the method described here is defended on the basis that validation was a group activity, and the same nominal group members had attended the interviews. The moderating effect created by working as a nominal group is considered to bring attendant risks of misinterpreting what had been discussed at the interviews. This risk is considered acceptable, although comparison of the validated products, with *cf* without interviewee input, was <u>not</u> conducted. Where they occurred, disagreements about the concepts and linkages were argued through to the point where the final form of the map was acceptable to all. Some differences of opinion remained, and ultimately these had to be accommodated. By adopting this approach, the nominal group produced a summary of their hypotheses rather than those of the original interviewees. Care was taken to ensure that the nominal group review meeting was held as soon as possible after the interview. This normally commenced within 20 minutes of completion of the interview. Whilst the maps produced this way cannot be considered to fully reflect the individual views of interviewees, they are considered to reflect a shared understanding amongst the PR&E team, and as such were accepted as sufficient summaries of the problem situation.

Figures 9-3, 9-4 and 9-5 capture a series of discussions the team had, although in these the focus tended to fall on various process issues. Despite this, they were useful in establishing the basis for subsequent discussions. It was not until Figure 9-6 was being ‘fleshed out’, and validated according to the schema at Table 7-2, that the most important PR&E issues began to emerge.

Whilst discussion started with considerations of extant and nascent processes, where the latter were anticipated to be cures for current problems, discussion soon moved to more critical analysis of cause and effect. In order to build concept maps it was necessary to have the team present their views, and argue in terms of cause and effect. It was a continual challenge to re-focus the team members' thinking in terms of cause and effect.

This was achieved during the development of Figure 9-6, when it mattered. The team acknowledged that it was necessary for managers to develop corporate understanding of the dynamics of program and project management. They acknowledged the need for an understanding of business dynamics, and that DAO's business was dynamic (Concept 53). Once this was recognised, and understood by executive managers, selection of procurement strategy (Concept 12) and selection of the 'most appropriate' KPIs (Concept 35) for monitoring project performance, could follow. Unfortunately the team, specifically, and DAO, generally, were not equipped to analyse projects that changed over time other than by taking a series of static snapshots, as would be reported through ProMIS: these snapshots were produced at the end of monthly or quarterly reporting periods. Discussion then moved to the reporting of KPIs through ProMIS.

The team agreed that it was necessary to add Concepts 53, 54 and 55 to the map. But, there was still a strong tendency to hold on to nascent processes as a way of correcting current problems, despite there being no clear basis for such assertions about the likely effectiveness of any new process. Familiar extant processes and procedures had long been documented in the Capital Equipment Procurement Manual (CEPMAN) (DoD, 1990) and discussions continually tended to revert to considerations of CEPMAN process and procedure and what might replace those.

There had been no modelling to assess how effective nascent processes and procedures might be. The team argued that the testing would take the form of a series of 'pilot' implementations. Just how and when these would be conducted was not clear. What was known was that the PR&E team would not be responsible for the conduct of pilot implementations. It was anticipated these implementations would follow in the near future under the auspices of another team constituted specially for the purpose of managing those implementations.

Given the earlier case studies and the literature review, it was suggested there was a need for testing of the team's hypotheses, embedded in Figure 9-6, through the building of system dynamics models.

9.16 Traditional KPIs – Schedule and Cost Variances

A pivotal activity of the PR&E area of the BPR initiative was to identify which Key Performance Indicators (KPIs) best informed executive managers about the achievements of project management teams and their projects. The PR&E team were keen to apply known and trusted KPIs. It seemed that the set of KPIs traditionally used would be relied upon in the post-BPR situation.

The fundamental basis for reliance on traditional KPIs, Cost Variance (CV) and Schedule Variance (SV) lies in the findings of a study conducted in the 1980s by the Joint Committee of Public Accounts of Parliament. Their report (JPAC 1986, Report 243) reviewed 16 Defence capital acquisition projects spanning the period 1979 to 1983 and found 11 out of 16 failed, or were predicted to fail to meet cost, schedule, or technical objectives. This report recommended (JPAC, 1986: v):

a. Recommendation 30: Cost Schedule Control Systems (CS^2) be introduced to assist contractors upgrade their management information systems.

b. Recommendation 31: CS^2 become the basis for cost and schedule reporting by contractors for all major projects.

c. Recommendation 30: Progress payments be geared to submission of satisfactory CS^2 Reports.

The relationships between the four main criteria against which project management effectiveness is measured namely, scope, quality, time, and cost, are shown at Figure 9-7. Regardless of the nature of the project, managers always need to know where the project stands in time and cost as measured by the original project schedule, and the approved project budget. Together these two constitute the project baseline.

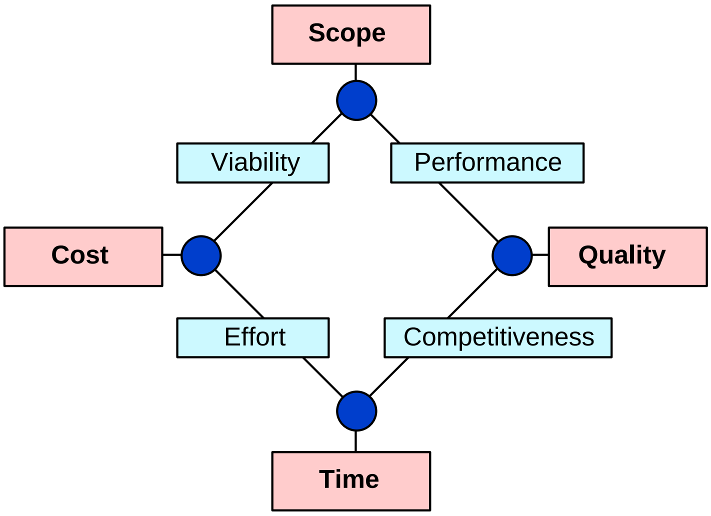


Figure 9-7 Relationship between Scope, Cost, Schedule and Quality in Project Management (1) (2)

Notes:

1. Reproduced from *The Revised Project Management Body of Knowledge*, Project Management Institute, USA.
2. Turner (1993: 12), explains that this diamond is sometimes represented as a triangle where *performance* is used to cover scope and quality.

The baseline normally takes the form of a Gantt chart, or time-based bar chart, depicting the major activities planned to be undertaken to complete the project. This is supported by a project budget, a baseline of known or estimated costs, based upon the Project's Work Breakdown Structure (WBS) (DoD, 1995). The CS^2 methodology has been developed to track two primary KPIs, CV and SV (Kerzner, 1995: 815, DoD, 1994a; 1994b). Once the WBS and the project budget are established the following are calculated as the work proceeds (DoD, 1990):

a. *BCWS*. Budget for work planned to be done during the reporting period. This is the project's baseline against which progress is to be reported.

b. *BCWP*. Budget for work done during the reporting period.

c. *ACWP*. Actual cost of the work done during the reporting period.

d. *SV*. BCWP – BCWS.

e. *CV*. BCWP – ACWP.

The general relationships are depicted diagrammatically in Figure 9-8, below.

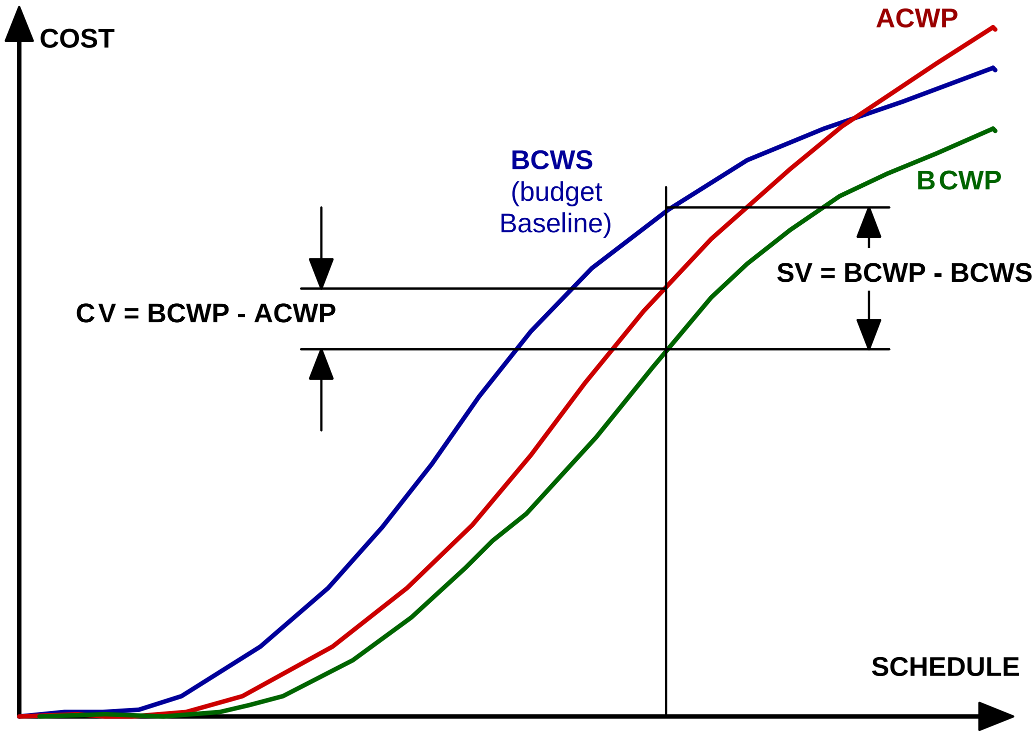


Figure 9-8 Cost and Schedule Variances in Monitoring Project Progress (1)

Notes:

1. Both SV and CV depicted here would be negative, that is, at the point in the schedule shown by the vertical line, the project is both behind in terms of both cost and schedule.

The earned value method of project performance monitoring, CS^2, was devised by the US Department of Defense during the 1970s and used for monitoring progress in fixed price contracts. It was adopted in the late 1980s by the Australian Department of Defence where it is used for monitoring progress in the management of variable price contracts. Cost Schedule Status Reporting (CSSR) is an evolution of CS^2 which is designed to reduce the effort required in reporting whilst still providing periodic reports regarding status against baseline cost and schedule.

When CV and SC are plotted on the same graph, a 'bulls eye' diagram is created. This is a most useful tool for monitoring project progress, particularly when used in conjunction with a specified tolerance for each of these KPIs. With careful selection of scales used on each axis, the tolerance can be simply drawn on the diagram as a circle. If the data for CV and SV for the relevant reporting period produces a point, which lies within the circle, then the project is within tolerance. If the point lies outside the circle, then the reasons for this need to be found. Use of such a diagram is demonstrated at

9.17, below. The general strategy advocated by the PR&E team was formulated on a relatively simple model that involved:

a. identifying the appropriate KPIs to be used;

b. establishing the tolerance to be set on these KPIs;

c. measuring performance against these KPIs;

d. monitoring progress, and when 'out of tolerance' behaviour was observed raising an exception report; and

e. investigating all exception reports.

For this PR&E strategy to work it was necessary that:

a. KPIs used be measurable and effective as indicators of performance;

b. tolerances be set to raise alarm when this is appropriate;

c false alarms be very infrequent;

d. data gathered be valid;

e. across a portfolio of KPIs and a portfolio of projects, the effectiveness of KPIs and tolerances produce consistent, faithful and repeatable results; and

f. exception reporting produce:

    (1) effective follow-up action;

    (2) be accompanied by an understanding of the causes of 'out of tolerance' performance; and

    (3) experiential learning that leads both to effective corrective action and enhanced project management.

9.17 Focus on a Particular Project AIR 5276 P3C Upgrade

The processes of capturing and reporting cost and schedule performance information in an acquisition project involving the capability upgrade of P3C maritime surveillance aircraft, were analysed.   The aim was to determine, in the context of PR&E, how faithfully actual progress made in this and similar projects, was reported. Given the following, it was clear that reporting cost and schedule variances would remain pivotal in PR&E:

a. Historical background which led to Defence's adoption of cost and schedule reporting, that is the recommendations of JPAC 1986, Report 243.

b. Reliance on information systems that provide visibility of the status of projects; Concepts 17 and 5 in Figure 9-3.

c. Achievement of visibility of project variances by senior management, Concept 1 in Figure 9-6, influenced at least by the following:

   (1) Ability to highlight 'out of tolerance' performance for closer scrutiny, Concept 42.

   (2) Effective performance measurement, Concept 27.

   (3) Identification of schedule variance, Concept 45, then consideration of consequences, Concept 44.

   (4) Identification of cost variance, Concept 6, then consideration of consequences, Concept 7.

A contract to modernise and upgrade the capability of ageing P3C Orion maritime surveillance aircraft was signed in January 1995. The Prime Contractor under this contract with the Commonwealth was E-Systems of Greenville, Texas in the United States. Later E-Systems would be subsumed in a take-over and become part of the Raytheon Systems Company. The contract price was approximately AUD$ 600 million.

The project plan was to upgrade the first aircraft at the Greenville, Texas plant, then complete the work on the remaining aircraft in Australia at Boeing's, ASTA plant, in Avalon, Victoria. In total 18 aircraft would be modernised and their lives extended until 2015. Airframes would be refurbished and lightened. Avionics and surveillance equipment would be replaced and upgraded to make this a world class, modern and effective maritime surveillance aircraft. This was a demanding systems integration project involving the following:

a. Surveillance radar from ELTA of Israel.

b. Navigation systems from Honeywell, USA.

c. Acoustic processors from Computing Devices Canada.

d. Data management system from Lockheed Martin, USA.

e. A systems engineering laboratory.

f. An operational mission simulator.

The prime contractor established a project management office in Canberra. This office has three roles, prime contractor, and local office representing the E-Systems and point of contact for the Defence project office in the Defence Acquisition Organisation. The parent company, E-Systems, was a sub-contractor to the Canberra-based office. Management aspects of the project were centred in Canberra with an on-site engineering team of Defence personnel based in Greenville, Texas. Sub-contractors in USA, Canada and Israel worked through the Texas office. In some cases there were sub-contractors worked to sub-contractors, who worked to the Texas office. This hierarchical arrangement for contract management and project performance monitoring is depicted in Figure 9-9, below.

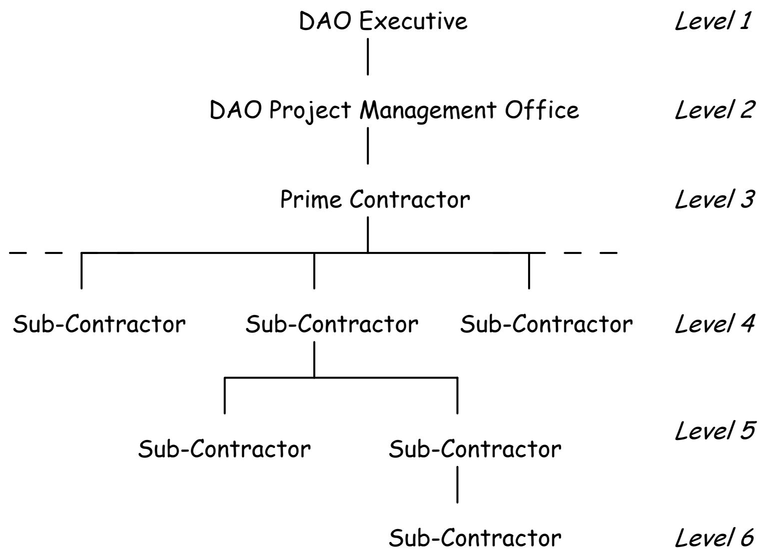


Figure 9-9. Levels in the Project Performance Monitoring Hierarchy

The project management activities were not totally resident in Canberra. A Cost / Schedule Business Manager position was created, and this person worked on-site at Greenville, Texas. The Cost / Schedule Business Manager was initially responsible for monitoring the CS^2 information from the prime contractor as well as the CSSR reporting that existed between the prime contractor and the sub-contractors involved.

A management decision made early in the project, recognising the size of the project and the nature of the systems integration work required, was to establish CSSR as the performance reporting framework between the prime and sub-contractors. It was expected this would provide sufficient visibility to the Canberra-based project management team of the status of the work being undertaken.

However, managing the CS^2 and CSSR reporting processes had not been without its difficulties. These difficulties were not fully appreciated within DAO, and certainly not at the DAO Executive level, for reasons that will be explained. The position of Resident Cost / Schedule Business Manager, Greenville-based, was abolished as an austerity measure just before the contract was signed. Subsequently, the importance of this position was accepted by DAO, whereupon a contract amendment was made and the position was established. But, it was almost another year before the position at Greenville could be staffed permanently.

The significance of failure to establish a fully functional cost / schedule reporting system across all contract and sub-contract offices from the outset was not recognised until some time later. Impacts included:

a. For quite some time there was no system that could collect all relevant data needed for efficient and effective reviews. Estimates made by the DAO project staff three years after contract signature suggested that the project was approximately 15 months behind the original contract schedule. The exact status could not be established, although DPMS staff of DAO were adamant that the cost / schedule information available to them gave an accurate summary of project progress.

b. Not all involved in the project were convinced that cost / schedule reporting was the most effective way of monitoring project performance.

c. Delays by some contractors to furnish cost / schedule data were assumed to have little influence on the validity of the data overall. For example, it was argued by DPMS staff, that the information would be incorporated in the latest reports, when the necessary data became available.

Whilst cost / schedule reporting had been implemented and the Resident Cost / Schedule Business Manager position was eventually established and filled, delays in compiling reports continued to occur. The way this information was being aggregated and reported should have placed the fidelity of Cost / Schedule Reports in doubt. In reality, little doubt existed, at least in the minds of the DPMS staff who routinely compiled the reports within 14 days of the end of the reporting period and passed the reports to the DAO Executive. DPMS justification of their mechanical process of compiling the reports was that it was being undertaken in accordance with the implementation guides (DEF(AUST) 5656; 5657), and that the implementation of Cost / Schedule Reporting in AIR 5276 had been accredited. Despite formal accreditation, processing delays and the aggregation of information of different vintages were occurring and this was problematic.

This was not recognised by DPMS staff, AMS staff, or the PR&E team. When the potential for delays was investigated, it was found that reporting delays for various work packages could range from less than 30 days, that is, within the reporting period, to 90 days or three reporting periods. The significance of this was only to become evident when a conceptual system dynamics simulation model was constructed. This model used dummy data rather than actual data. For reasons of commercial confidentiality, the data needed to fully populate a dynamic simulation model could not be made available.

It readily demonstrated that when delays in data collection and reporting occurred, and information as little as a few days old was aggregate with information months old, CV and SV as reported to DAO executives reviewing the project, bore little resemblance to actual progress. This is depicted in Figure 9-10 where the reported CV and SV are compared to the actual CV_{act} and SV_{act}. The head of each arrow depicts the performance, reported or actual, at the end of each reporting period.

At the end of the last period, where the square black dot is used to indicate reported progress and the round black dot to indicate actual progress. As depicted in Figure 9-10, the project was reported as being on schedule but slightly behind on cost, when in reality it was significantly behind in terms of both schedule and cost. The conceptual system dynamics model used to demonstrate the discrepancy between actual and reported, that is delayed, values of CV and SV, is at Annex B.

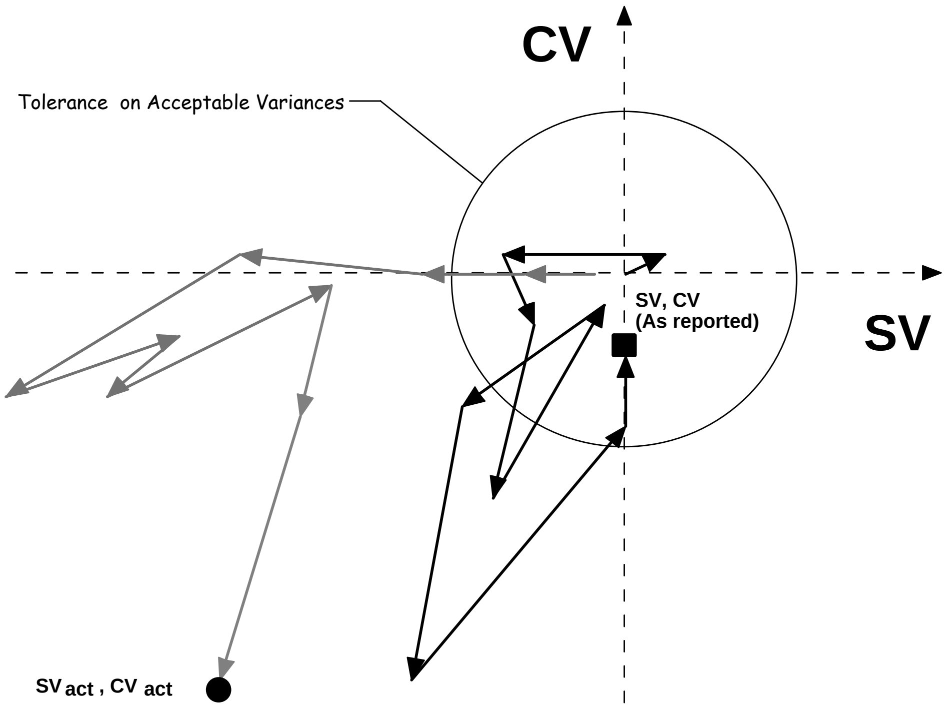


Figure 9-10 Relationship between Reported and Actual Schedule and Cost Variances

9. 18 Denial of the Existence of a Problem Situation

When the dynamic simulation model was demonstrated to the PR&E team, they were reluctant to accept what was being shown in a dynamic way could be the case. In part their incredulity stemmed from a lack of visibility of broader project management issues, such as those mentioned above. Further, they were unaware of the problems in relation to establishing and filling the Resident Cost / Schedule Business Manager position.

When the model was demonstrated to DPMS staff, their reaction was also one of incredulity. In their view, what was of prime importance was that all reports received from the prime contractor by DAO were processed within 14 days of the end of the relevant reporting period. It was now 39 months after contract signature, and DPMS staff assumed the prime contractor was processing cost / schedule reports on behalf of sub-contractors in a timely manner, and all data was drawn from the relevant reporting period. But, they had little visibility of delays that might be occurring in compilation of cost / schedule reports at the sub-contract levels, that is at Levels 4, 5 and 6 in Figure 9-9. Exceptions or problems in the conduct of the project were routinely reported, but these were likely to highlight technical issues rather than cost / schedule reporting delays such as those having an impact here.

DPMS staff also argued that the work packages assigned to sub-contractors were of lesser monetary value and, in any case, there was a certain amount of 'slack' in the project schedule. Whilst this was true in relation to the former point about the size and value of work packages as they were assigned to sub-contractors at levels 5 and 6, it was no longer true that there was any residual slack in the project.

Sub-contractor's work packages were not always of lesser monetary value, particularly at level 4, but in these cases reporting delays could significantly contribute to an erroneous view of overall progress in the project.

It is worrying that the existence of a problem was denied by DAO executives, despite evidence to the contrary. An important issue here is that implementation of CS^2 and CSSR did not cater for dynamics involved such as the various delays in the information gathering process. As a consequence, there were times when the accredited PR&E methodology produced results, which were both misleading and counter-intuitive. Under these circumstances, it may have been better to have no cost / schedule reports at all. Reverting to complete reliance on anecdotal evidence produced by the Project Director may have been a more valid way of gauging progress being achieved in the Project. However, complete reliance on a process based on CSSR and CS^2 that was fundamentally robust, but flawed in its implementation, proved to be problematic.

9.19 Retrospective on Performance Reporting and Evaluation Framework

Any concept map produced can only be a partial view of a whole problem situation. Further to the discussion at 9.17 and 9.18, above, and referring back to Figure 9-6; the Cost / Schedule Reporting delay problem is a systemic one despite there being no obvious feedback loops. This becomes clear with the addition of a new concept *level of resourcing available for Cost / Schedule performance monitoring.* In effect, this delayed feedback loop was completed when a decision was made to establish and staff the Cost / Schedule Business Manager position. A virtual loop always existed despite the level of resources in this case being zero.

The characterisation of 'wicked' problem in Chapter 5, as drawn from the literature and the case studies in the early chapters leads us to look for the incomplete feedback structures.

Provision of a Cost / Schedule Business Manager at Greenville, Texas, from the outset, might have obviated the Cost / Schedule monitoring and reporting delays. The effect of adding this new concept is summarised at Figure 9-11, below.

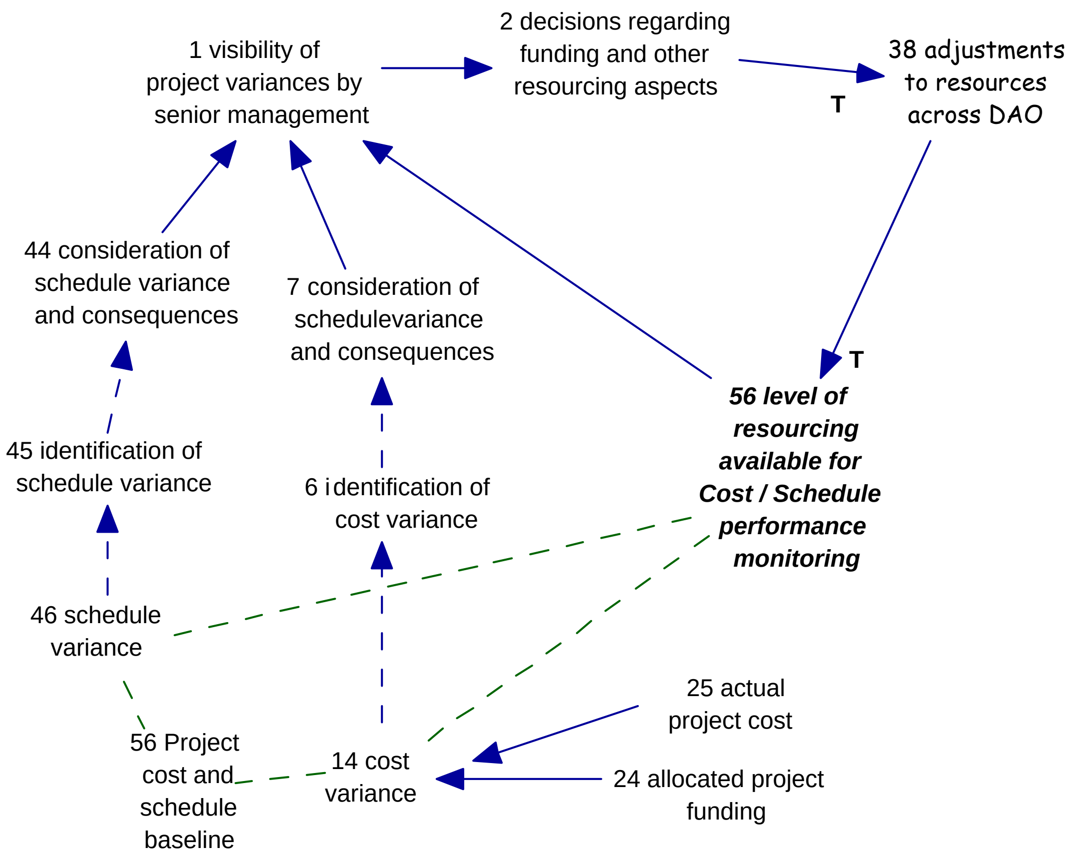


Figure 9-11 Feedback Structure in Updated PR&E Framework

9.20 Increased Reliance on Business Information Systems Support

Throughout the conduct of this research, an increased reliance on business information systems support was proffered as the panacea for virtually all pre-existing ills in PR&E. The extent to which reliance on business information systems is justified is dependent upon the validity of the data, the data gathering methods, and the means of analysis used. This case application, albeit a narrowly focused one, showed that erroneous performance monitoring processes may not be readily identified for what they are, especially when the focus is on process rather than systemic behaviour.

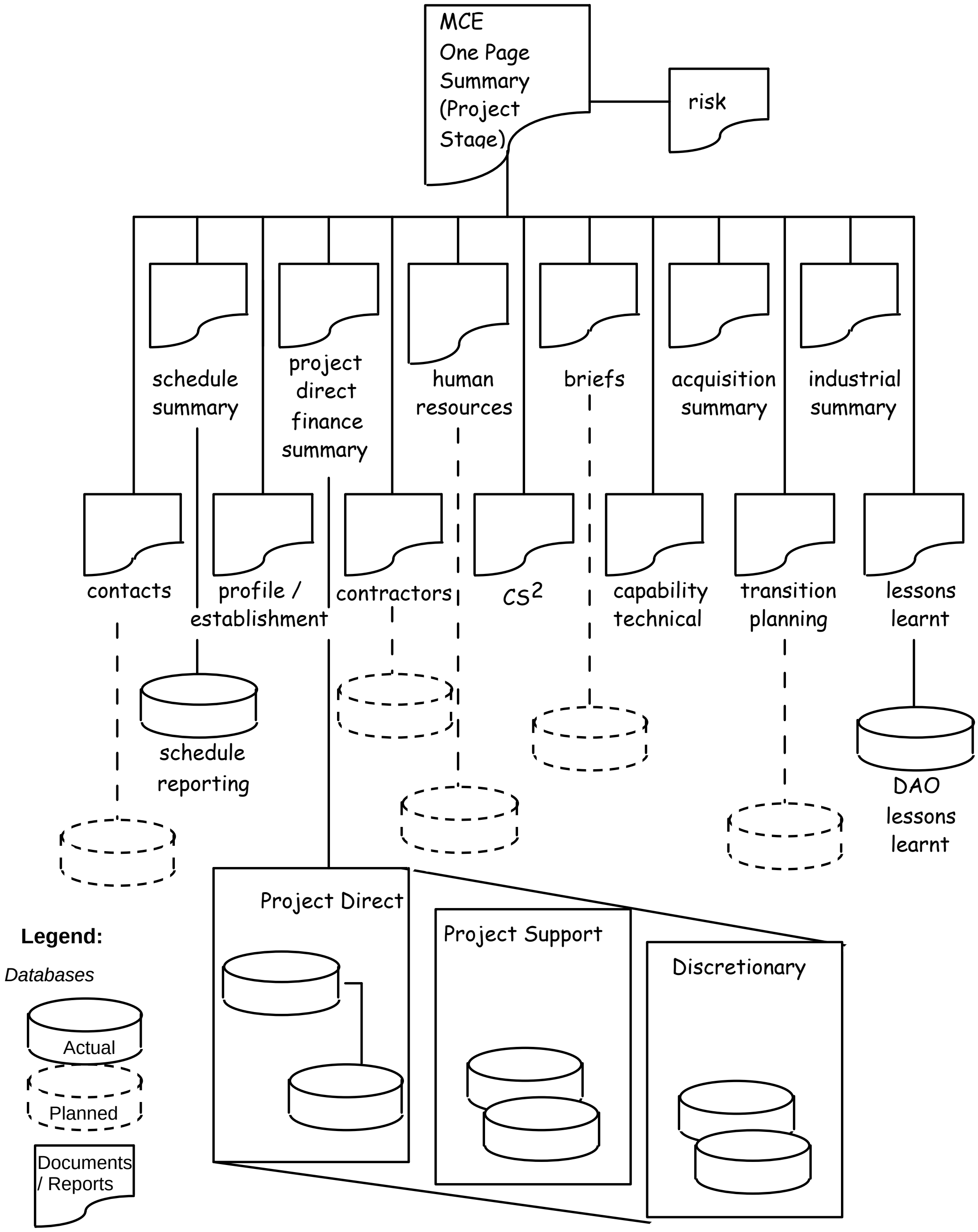


Figure 9-12. Structural View of Project Management Information System – ProMIS (1)

<u>Notes:</u>

1. This diagram shows the physical separation of databases and content, not the navigation connections. Project and non-project details are held in physically separate databases.

A summary of the changes to business information systems support planned at the time this research was conducted is contained at Figure 9-12.

Increasing the reliance on business information systems support, by itself, is insufficient. Business information systems must provide support to the extent needed by executive decision-makers. Those decision-makers must understand both the detail and the dynamics of the business systems they are responsible for managing.

9.21 Application of IISD - A Case Study in Reliability Prediction

A case (McLucas, 1999) involving the application of IISD in a project management context, where reliability prediction became an issue of concern, is included at Annex C. This application of IISD was free of the exogenous constraints such as those applied in the BPR case. Specifically, there were no artificial limits placed on access to relevant stakeholders by gatekeepers. As a result, qualitative and quantitative techniques were used to aid learning about another deceptively difficult problem.

The outcome of IISD was a significant change in the way stakeholders viewed the problem. Evidence to support this claim can be found in the logistic support strategy developed as a direct result, and immediately implemented. As a result of this implementation, the time taken to restore the satellite communications was reduced: the available repair parts were held where they were most likely to be needed. The specified level of availability across the whole network was achieved and maintained from this point onwards. This case application followed the tutorial example very closely and, unlike the BPR case where unnecessary constraints were applied, proved to be highly successful.

Lessons drawn from this case application are:

a. By itself, qualitative modelling can be a valuable aid in revealing where to apply management effort. Often, quantitative analysis is sufficient for developing strategy options, though qualitive analysis is often needed to discriminate between those options.

b. As a decision-support tool, dynamic simulation modelling suffers from the disadvantage that building models takes time. Unless models can be built quickly with high levels of confidence, they are likely to be of little use. A sophisticated model produced late is of no use. This means models have to be relatively simple yet must provide powerful insight.

c. Models must be constructed to enable ‘what if’ questions to be answered easily and effectively. One of the most effective ways of accommodating such questions is to build a management flight simulator interface, which facilitates input of the most influential variables over a range of values.

d. Models must be scalable, either up or down in size. After initial validation, conversion of models to array versions makes models much more generally applicable. For example, the tutorial model in Chapter 7 was built as an array model and so enabled analysis of the varying numbers of trucks. The number required was simply chosen using a slide control on the management flight simulator. Similarly, in this reliability prediction case, the model was easily scalable because of its modular construction.

e. Models must be modular. Modular models are easier to debug and to validate.

9.22 Summary - Chapter 9

Two case applications are described in this chapter. Success achieved varied according to the extent to which the methodology described in the tutorial, at Chapter 7, was followed. In the BPR case application, exogenous constraints on the use of IISD made it less successful than it might have been otherwise. Whilst the efficacy of IISD was demonstrated, the PR&E aspects of the BPR intervention were not so successful. Such constraints are a real threat to IISD, to action learning and to action research. The second case application, which did not suffer from these constraints, was highly successful. Lessons from these case applications were recorded.

9.23 Significant Contributions Made in Chapter 9

The cases described in this chapter are practical examples of the application of qualitative and quantitative analysis in aid of business strategy development. By using the IISD action research approach it is practical to start from a point where the nature of the problem is either not well understood, or is misunderstood, and step-by-step move through to the development of real understanding upon which effective remedial strategies can be developed. The significance of these case applications is that they build on lessons and understanding of systemic behaviour established in the case studies at the beginning of this dissertation. IISD enables identification of where to apply management effort to achieve greatest effect.

CHAPTER 10: CASE APPLICATION: DEFENCE PREPAREDNESS

Synopsis

This chapter describes the Defence Preparedness Resource Modelling (DPRM) project. DPRM was conceived to provide decision-support to managers of Australia's Defence preparedness. Unfortunately, the DPRM project failed: implementation never occurred. An inexperienced project manager pursued a management strategy giving superficial treatment to problem conceptualisation. Independent advice regarding system dynamics modelling methodology, provided by the University of New South Wales, was ignored.

Senior ranks of the Armed Services and the ADO Executive, remained aloof. Their involvement in conceptualisation, problem definition, and model building was scant. Double-loop learning, through 'modelling as learning', only became a reality for a select few, those closest to the modelling effort. Some remained unconvinced of the applicability of system dynamics modelling, and veracity of models created. An appreciation of what DPRM was capable of delivering was also lacking. There was an expectation that dynamic modelling would complement activity-based accounting. Publicly there was support for DPRM because Parliament mandated that Preparedness be 'modelled' and the Australian National Audit Office (ANAO) would ensure some form of quantitative modelling was done. Some stakeholders had vested interests in decision-support systems being developed separately in their own domains of action. They became gatekeepers, controlling access to data needed to populate DPRM models.

Late in the project, the DPRM Director agreed to revisit problem conceptualisation. At this point, with the aid of the author of this thesis, an attempt was made to apply IISD to this most important, politically sensitive project, but it was too late. The main research outcomes were identification of the need to correctly scope the intervention and clearly specify intended outcomes, identification of forces militating against modelling projects, the need for stakeholder management, and the critical importance of completing every step of a rigorous 'best practice' modelling methodology.

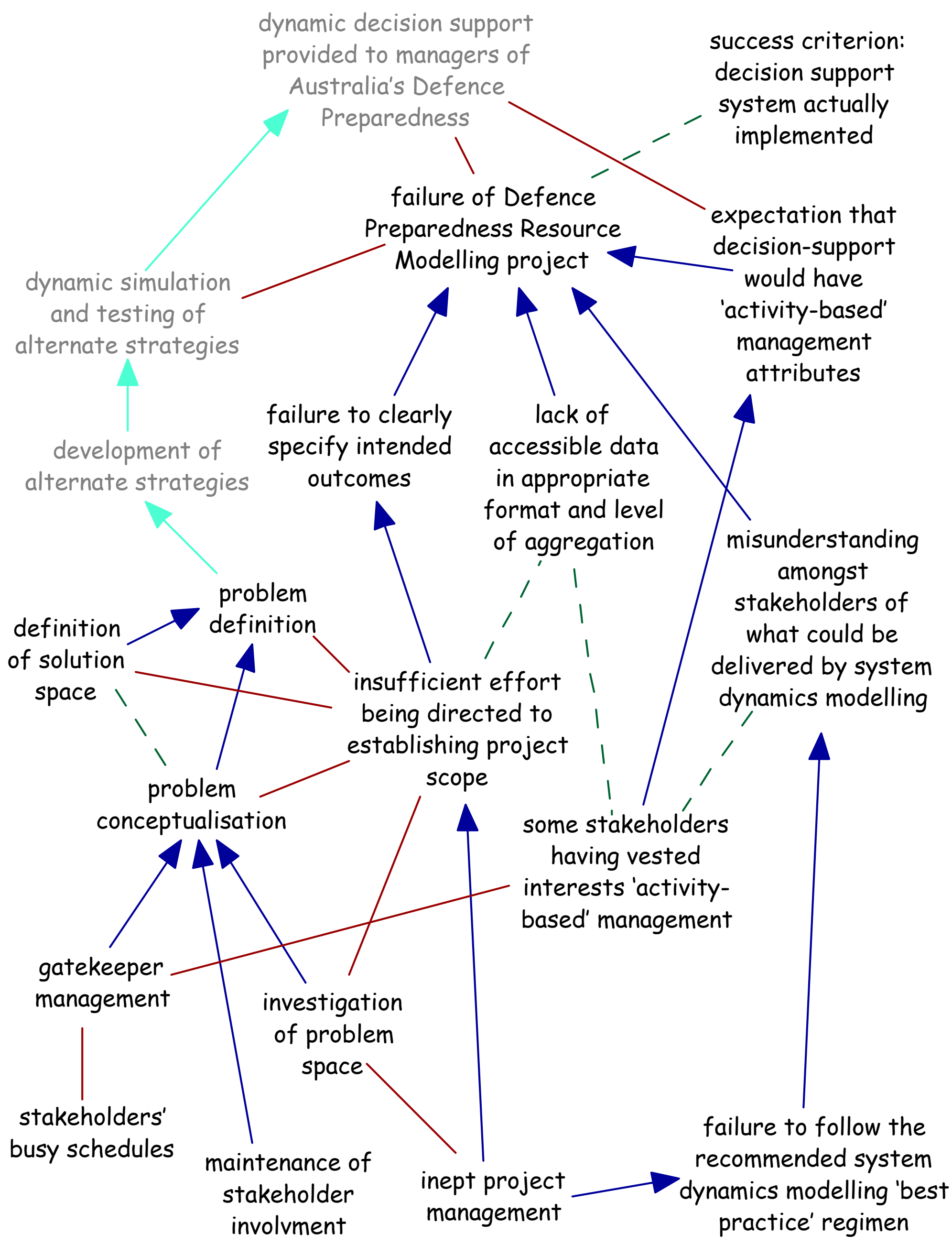


Figure 10-1. Concept Map – Chapter 10 – Synopsis

In their 1996 report on the management of ADF preparedness, the Australian National Audit Office (ANAO) emphasised the need for reliable and accurate assessments of resource requirements in military planning. ANAO was critical of the ADF's inability to provide estimates of the costs associated with making Force Elements (FEs) and Force Element Groups (FEGs) ready, and sustaining them. ANAO noted that the ADF experienced difficulty in making the required calculations, and could not do so with confidence. This chapter describes the conduct of an initiative, the Defence Preparedness Resource Modelling (DPRM) project, intended to correct what ANAO had been critical of, and an attempt late in the project to use cognitive mapping as an aid to reviewing problem conceptualisation.

10.1 Mission of the Department of Defence

The mission of the Department of Defence is depicted at Figure 10-2, and explained below.

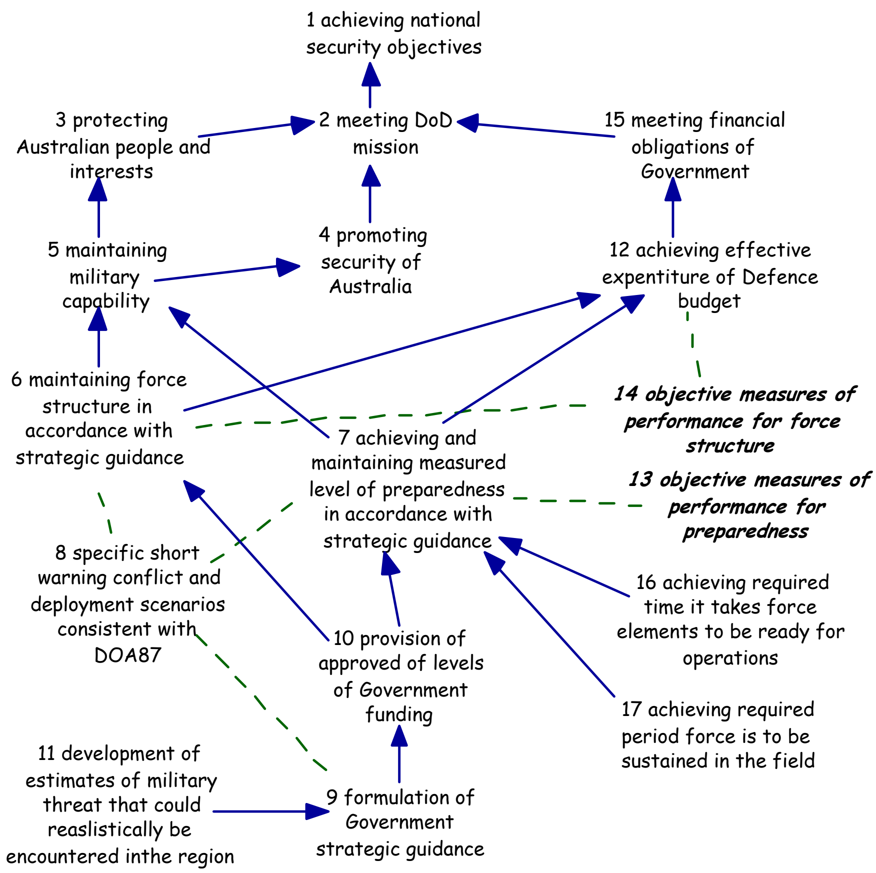


Figure 10-2. Department of Defence Mission

> … to promote the security of Australia and to protect its people and interests… by maintaining the military capability required to implement the strategic guidance received from Government. This capability is achieved through a combination of force structure and the preparedness of that structure for operations. Preparedness relates to the time it takes force elements to be ready for operations and the period for which they can be sustained in the field. These matters are central not only to national security, but also to the effective expenditure of a significant proportion of Defence's annual budget of around $10 billion. Because preparedness represents a fundamental output of the Australian Defence Force (ADF) it is important that appropriate processes are in place to enable it to be managed effectively… (ANAO, 1996: 3).

10.2 Concerns about ADF's Capacity to Manage Preparedness

ANAO conducted a preliminary study to gain an understanding of the concepts and associated processes used in the management of preparedness, including the methodology used to translate Government's strategic guidance into military capability. ANAO studied the processes by which Services translate preparedness directives into operational requirements; and how HQ ADF and the three Service Offices assure themselves that FEs and FEGs can satisfy the requirements of preparedness directives. The ANAO acknowledged that preparedness is a complex and dynamic concept, noting:

a. to manage preparedness effectively:

   (1) Defence must be prepared to adjust preparedness criteria under rapidly evolving circumstances; and

   (2) Defence's preparedness management framework required considerably more development;

b. whilst, inevitably, judgements have to be made, Defence should ensure that the determination and implementation of preparedness requirements results from coordinated and rigorous consideration of <u>all</u> relevant issues;

c. identifying all such issues and establishing appropriate priorities is a difficult task, which:

   (1) must consider the risks appropriate to operational and resourcing decisions; and

   (2) should make allowance for significant variations in respect of basic

assumptions as potential conflict scenarios develop (ANAO, 1996: 4-5).

ANAO's preliminary findings are summarised at Figure 10-3.

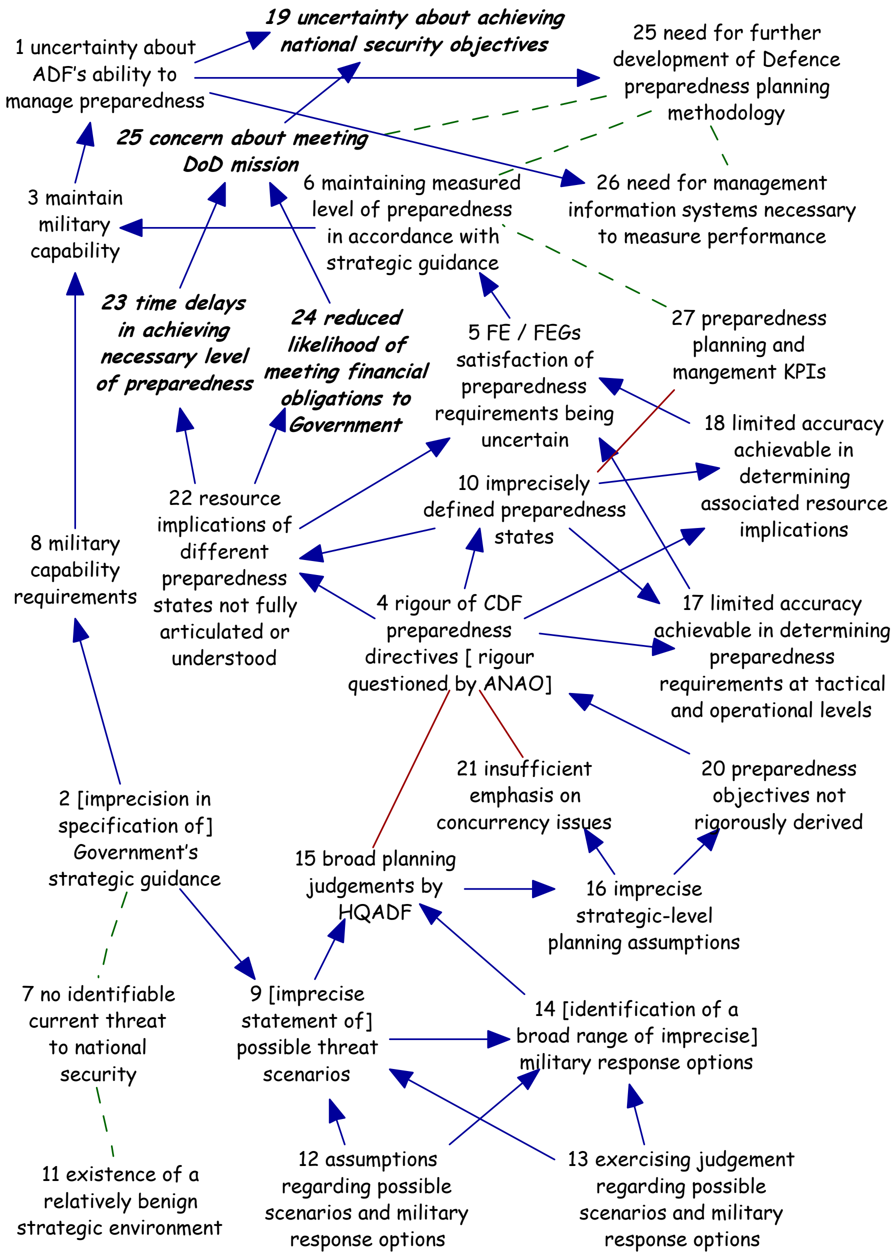


Figure 10-3. ANAO Preliminary Finding

The Defence Efficiency Review of 1997 was also highly critical of the ADO and its management of preparedness, noting:

> … Defence's comprehension of the time and resources required to generate forces is deficient, as is its understanding of the relationship between activity levels, associated resource requirements and the achievement of preparedness objectives (DoD, 1997b: 81).

10.3 Achieving Balanced and Effective Military Capability

Renowned commentator on Defence issues, and Director of the Australian Defence Studies Centre, Alan Hinge, makes the following observation about balancing the military capability equation:

> The challenge of achieving optimum military capability, for a given budget, is striking the right balance between preparedness (consumption) and force structure (investment), over many years. However, getting the balance right is tricky because of the dynamic tension between preparedness and force structure [and the elements of each]… if we buy more of one ingredient, we get less of the other (Hinge, 1998: 5).

The relationship between force structure, preparedness, and military capability is outlined at Figure 10-4, below.

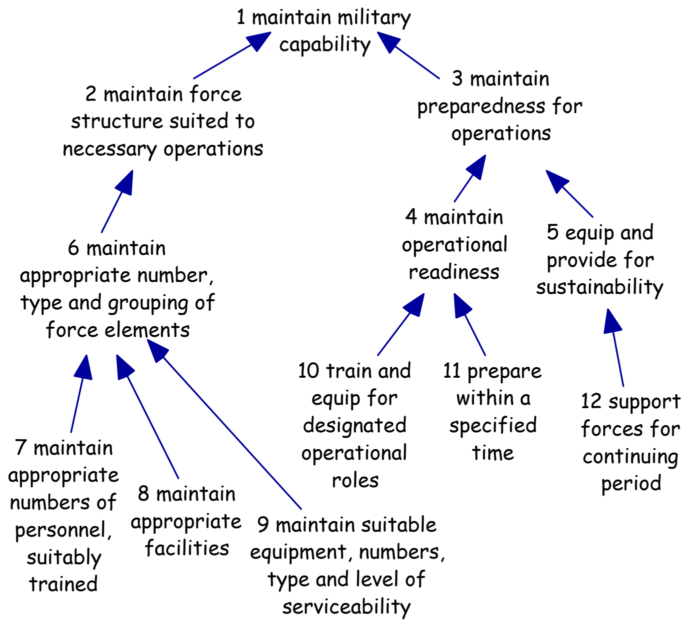


Figure 10-4. Basic Model of Force Structure and Preparedness in Military Capability

Preparedness management and force structure development are inextricably linked. As Hinge observes, they are constrained in their totality by the Defence budget. Management of defence capability is not only a matter of balancing the two sides of the equation. The Defence Executive, ANAO and Government are interested in the total cost of maintaining military capability, of which Preparedness is only one part.

10.4 Background to DPRM

Defence's Chiefs of Staff Committee (COSC) discussed the resource implications of preparedness in March 1995 in relation to experience gained in the work-up to Exercise Kangaroo 95. Concern was expressed that the ADF was unable to relate resources to preparedness and to provide cost assessments in which the ADF could have confidence. In August 1995, the DPRM Steering Group approved a statement of requirements for the conduct of the DPRM project. These requirements were refined in October 1996 by the DPRM Working Group, the group responsible for detailed management of DPRM.

In February 1997, the University of New South Wales (UNSW) System Dynamics Group was tasked to develop a set of prototype models to demonstrate the technical feasibility of modelling, and to provide a foundation upon which DPRM might be built. Prototype models of the Aviation Support Group, Submarine Squadron and other selected FEs were built during 1997. These models were demonstrated to members of the Defence Executive up to the 2-star level, that is Major General rank or equivalent. Acceptance of these models and the UNSW modelling methodology became the basis for proceeding with DPRM.

10.5 Aim of DPRM

The DPRM Project aimed to develop a decision-support tool, which linked inputs of basic resources such as personnel, training, equipment, and maintenance support to the achievement of specified levels of preparedness. The general relationship between personnel, training and equipment factors in preparedness, is depicted as an influence diagram at Figure 10-5, below.

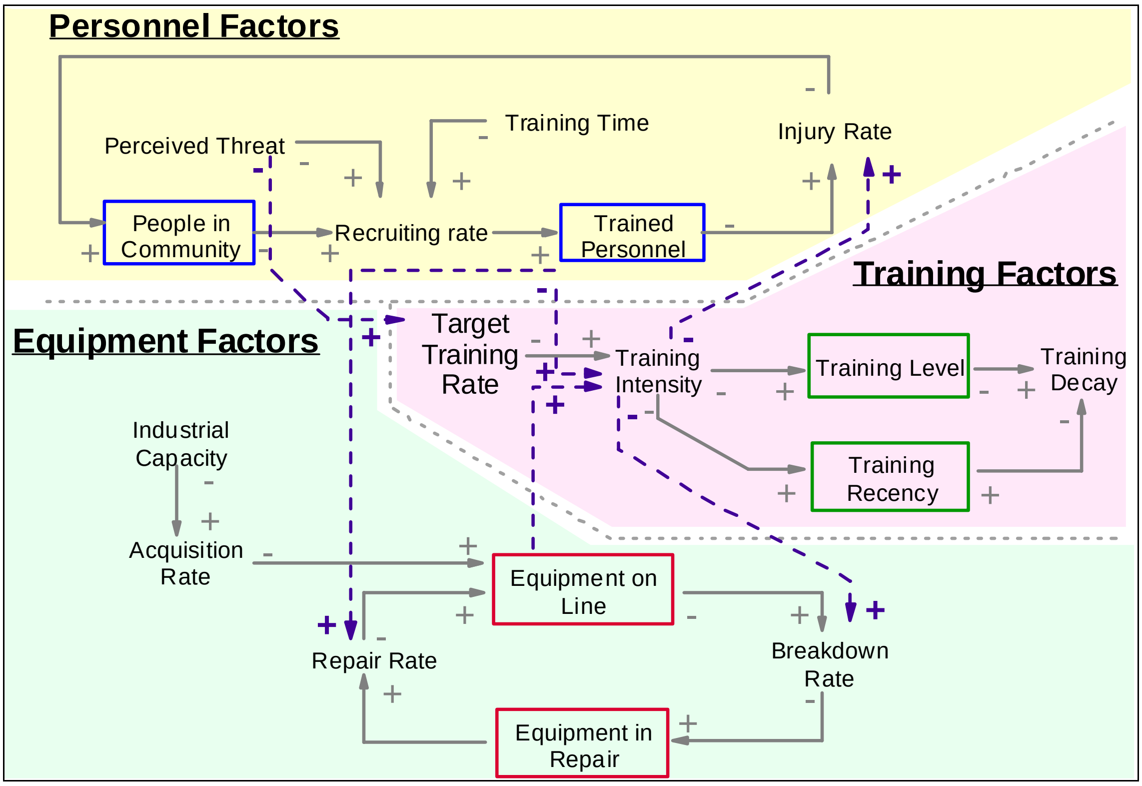


Figure 10-5. Relationship between Personnel, Training and Equipment Factors (1)

Note:

1. McLucas and Linard (2000).

In Preparedness planning and management, three levels of Readiness are of interest:

a. Operational Level of Capability (OLOC). OLOC is that required for conduct of operations. OLOC is the highest level.

b. Maintenance Level of Capability (MLOC). MLOC is that expected to be achieved in a long-term Readiness maintenance program.

c. Present Level of Capability (PLOC). PLOC is the extant level. Most frequently, this is less than MLOC, noting that levels drop as a result of periods of inactivity by FEs and FEGs. The difference between PLOC and MLOC is the current capability gap.

The relationship between Preparedness and its constituent components, Readiness and Sustainability is depicted at Figure 10-6, below.

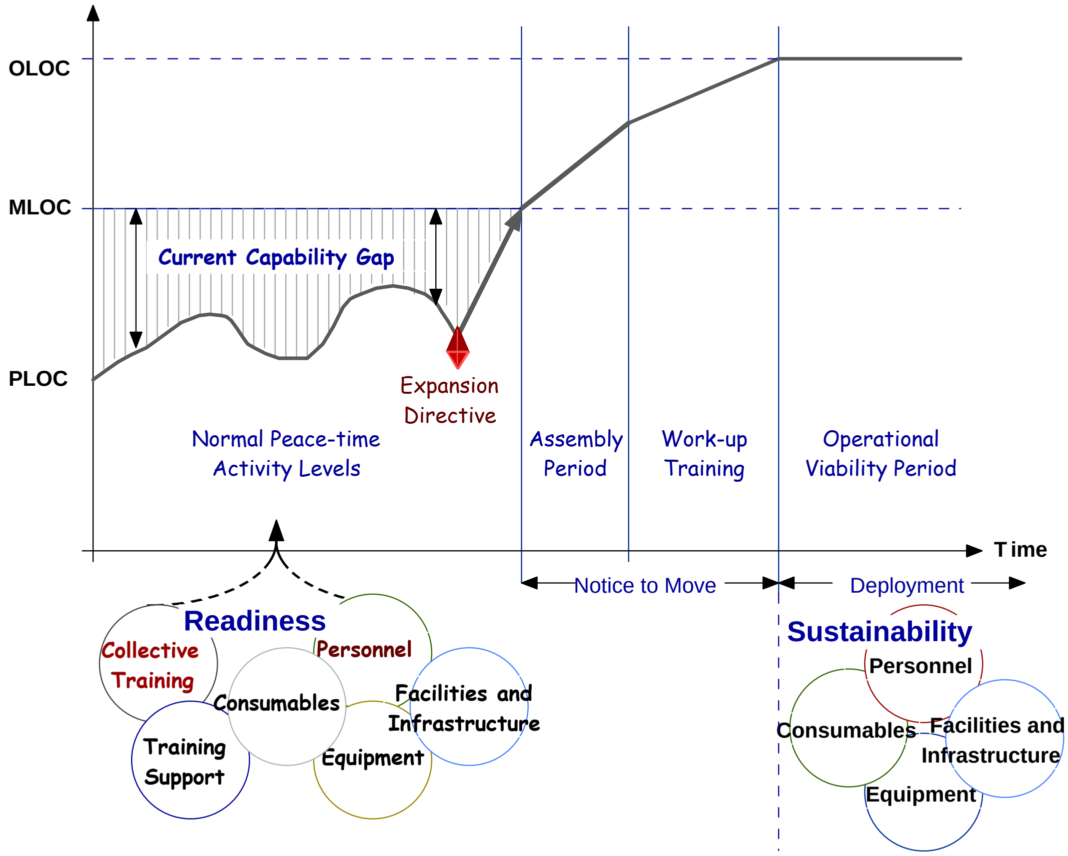


Figure 10-6. Readiness, Sustainability and Preparedness (1)(2)

Note:

1. Terms are defined in Australian Defence Force Publication No 4.

2. The graph shows the variation of PLOC against the target maintenance level, MLOC, up to the point where an Expansion Directive is issued. At that point efforts are directed at achieving OLOC by the planned Deployment Date. Beyond that date the Force Element (FE) or Force Element Group (FEG) is expected to be operationally viable, and OLOC sustained.

Preparedness is contingent upon having the necessary resources available when needed. Figures 10-5 and 10-6 suggest that achieving preparedness is dynamically complex. Not immediately obvious are the diverse activities and varied delays in concurrent activities that make Preparedness management difficult. The cost of maintaining PLOC levels close to MLOC for long periods, for diverse FEs and large FEGs, can be a major drain on Defence operating costs.

The imperative for managing Defence Preparedness must be considered in the context of the mission of the Department of Defence, and the Defence budget, overall.

10.6 Initial View of DPRM Project

ADO initiated the DPRM project, envisaging the prototype decision-support system as a simulation game capable of exploring the impact of decisions to create required levels of Preparedness. Initially, DPRM was to draw data from:

a. various activity and planning databases available across the whole of the ADO;

b. the personnel, training, equipment and maintenance databases operating in the individual Service domains and specific programs within the ADO; and

c. the Activity Based Management systems of the individual Services.

10.7 Problematic Initial View of DPRM

Although it was not evident at the outset, the initial view of the project expressed at 10.6 was problematic, because:

a. Assumptions that system dynamics would draw input from and provide valid, quantified resource ‘accounting’ output in a way similar to activity-based accounting, seriously constrained thinking about the dynamics of preparedness.

b. Some stake-holders had expectations that system dynamics modelling could validate budgetary information. This is an inappropriate use of system dynamics modelling: models contained stochastic attributes. Further, as Sterman (2000: 846) points out that whilst system dynamics models can be tested for their fidelity in replicating observed behaviour, they cannot be validated, that is, objective truth is impossible to establish by modelling and model behaviour cannot be established as ‘truth’.

c. Modelling is most valuable for fostering learning, and providing insights, about the behaviour of dynamic, complex systems. Activity-based accounting in the ADO is ‘stove-piped’, that is, resource sums are calculated vertically within each of the Services or Programs, or with respect to specific activities such as major Defence Exercises. Ignoring the strong coupling of activities which transgress organisational boundaries is contrary to system dynamics principles. However, some stakeholders saw system dynamics modelling in this activity-based accounting role. Later, others would use the inability of system dynamics modelling to provide activity-based information, to discredit both system dynamics and DPRM.

Even at the time the project was closed, there was an expectation that system dynamics modelling might have provided activity-based accounting information. In the DPRM Project Closure Report, it was noted:

> An ‘executive information system’ phase of DPRM was planned but never began because Defence Activity Based Management emerged as the most suitable project to subsume the DPRM concept (Un-referenced DoD DPRM Project Closure Report, dated Sep 99: 3).

Such expectations should have been revealed early in the project, through rigorous problem conceptualisation involving key stakeholders. They were not! Had required effort been directed toward conceptualisation, such expectations would have been identified and the project may have been abandoned, see Figure 6-5, or a totally different approach taken.

10.8 Recommended Approach to DPRM

The UNSW System Dynamics Group made recommendations concerning project scope, modelling methodology, project management and risk management. The Group’s report to the ADO emphasised that system dynamics modelling typically involves systemic problem situations that have defied traditional interventions. Understanding of the problem context and the identification of interrelationships and possible intervention pressure points are more important than the end product, the model. Accordingly, defining scope, problem conceptualisation and model building tend to be iterative processes (Homer, 1996; Sutton, 2000), with mutual learning between the modeller and the client (McLucas, 1998; Morecroft and Sterman, 1994; Vennix, 1996). UNSW recommended the following seven stage iterative framework, based on experience and drawing on Checkland (1993), Coyle (1996), Richardson (1981), and Wolstenholme (1993):

<u>Stage 1</u>: Project Planning	<u>Tools include</u>: Text & flow charts, project, configuration and risk management tools. <u>Modelling Focus</u>: Project scoping and outcomes definition. Identification of deliverables, timeframe and budget, skills required and team specification, development of project management schedule, and development of a risk management plan. <u>Client Focus</u>: Confirm scope and deliverables with client. Clarify

	client's understanding of SDM. Clarify project expectations.
<u>Stage 2</u>: Problem Conceptualisation	<u>Tools include</u>: Text and graphing of 'reference modes of behaviour', causal loop or influence diagramming, development of SSM root definitions and 'rich pictures', 'hexagons', cognitive mapping, review of previous reports on application of systems thinking and problem conceptualisation.
	<u>Modelling Focus</u>: State 'problem' contexts, symptoms and patterns of behaviour over time. Restate 'problem', for example, using SSM. Identify basic organisation structures and core business processes, identify outcome performance measures, identify patterns of resource behaviour over time, identify system boundaries and time horizon, identify feedback relationships, identify key 'resource states' and associated flows, identify key information and material delays, identify key interrelationships.
	<u>Client Focus</u>: Confirm understanding of business with client. Confirm understanding of the 'problem' with the client. Clarify client's understanding of 'dynamic problems'. Confirm organisation performance measures with the client.
<u>Stage 3</u>: Model Formulation	<u>Tools include</u>: System dynamics software. Output graphs and associated tables from the system dynamics models.
	<u>Modelling Focus</u>: Develop initial prototypes following an iterative process: *map – model – simulate – validate – reiterate*. Develop high-level system 'map'. Build basic 'stock-flow' model of key business processes, limiting models to 20 - 40 variables depicting key stocks, that is preparedness resources, and associated flows. Include carefully selected auxiliaries, resource performance targets, key performance indicators, key information and most influential material feedbacks and systemic delays. Where there are a variety of core processes in the organisation, they may need to be developed as independent sub-models.
	<u>Client Focus</u>: Confirm basic logical structure and model functioning with client. Confirm key variables. Confirm business rules that need to be embodied in the models.
<u>Stage 4</u>: Model Development	<u>Tools include</u>: System dynamics software. Output graphs and tables.
	<u>Modelling Focus</u>: Develop detailed prototypes following an iterative

	process: *map – model – simulate – validate – reiterate*. Iteratively elaborate model, challenging system boundaries, validating stocks, flows and auxiliaries, validating business rules being cognisant of balance between complexity and simplicity. Add multi-dimensional arrays if applicable. Identify and build policy levers and report generation, noting variables relevant to decision makers. Provide output reports tailored for decision makers. Client Focus: Confirm basic structure, logic, key variables, interpretation of business rules, and included parameter, values with subject matter experts.
Stage 5: Model Validation	Tools include: Historical data, especially comparison with output graphs and tables. Modelling Focus: Quality Assurance, verification and validation, testing, and iterative revision of models. Client Focus: Confirm model outputs with subject area experts. Independent verification and validation, and model testing.
Stage 6: Model Handover.	Modelling Focus: Installation and training. Ensure model links with extant information systems. Ensure compilation of quality user manuals. Client Focus: Confirm model works in client environment. Confirm client can operate models and interpret outputs.
Stage 7: Model in use.	Modelling Focus: Model use and fine tuning. Client Focus: Evaluate model against original criteria.

UNSW 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.

10.9 Actual DPRM Modelling Activity

In April 1998 a request for tender was issued. The Defence Department subsequently hired a technically competent system dynamics consultant who had domain knowledge of Defence Preparedness. The contract simply provided for supply of labour. The Defence Department managed DPRM as a minor project, specifically excluding the contractor's suggestion that the project be run in accordance with their accredited ISO

9000 quality management procedures. Not until late in the project did the Defence Project Manager employ formal risk management and a structured project management methodology. The system dynamics methodology, recommended by UNSW was largely ignored. Instead, the project manager launched forthwith into model development. The consultant was directed to prepare three joint combat capability models (Land, Air and Maritime). See Figure 10-7.

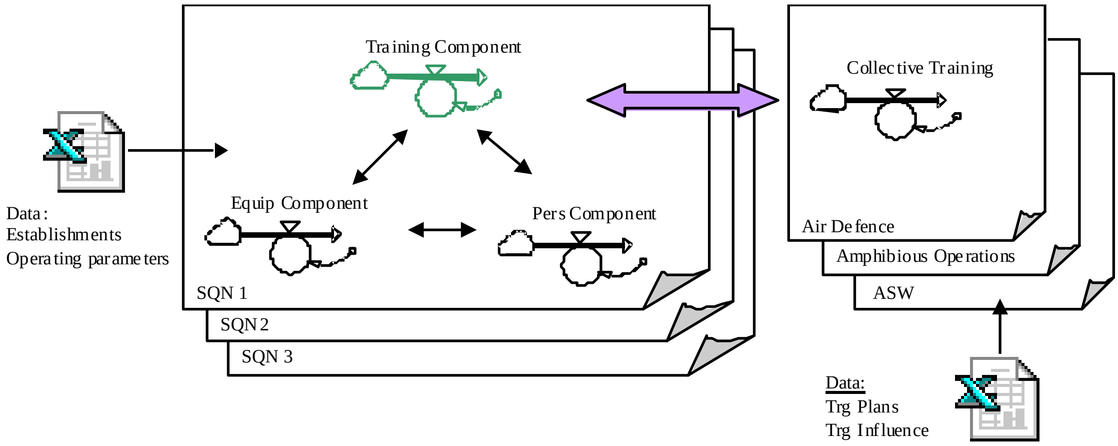


Figure 10-7. DPRM Joint Capability Models - Overview (1)

Note:

1. DPRM system dynamics models created were nationally classified. Details of the models could not be provided in this thesis.

The project was controlled tightly by the Defence Project Manager who reported frequently to the Preparedness Working Group, with representatives from stakeholder groups across the ADO. The Preparedness Working Group obtained Service input, through a series of technical workshops. According to the DoD DPRM Project Closure Report (1999: 4), this approach was implemented as a way of mitigating risks. The effect was contrary to what was intended. It served to fragment modelling activities, created ‘stove-piped’ views, and precluded the modelling consultant developing models representing an holistic view of Preparedness.

The consultant produced a number of technically sound and highly innovative system dynamics models. Models designed to examine how the tactical fighter group, surveillance and ground based air defence units interact to provide air defence of forward air bases were independently evaluated, against the RAND criteria, by the Defence Science and Technology Organisation (DSTO) (Brunskill and Cox, 1999):

reflect what forces do, not just what they have- The system dynamics approach takes into account what the forces are required to do. What the forces are required to do was determined from extensive interviews with senior officers of the FEGs concerned. Thus, readiness is measured in terms of judgements on the level of skill needed, etc.

be practical (ie non-disruptive, inexpensive and understandable)- Any technique, which requires special data not collated and maintained for other purposes, runs the risk of being disruptive and expensive. Little effort was made prior to the development of DPRM to scope where the data sources would be or who would maintain them. This is not because system dynamics is inherently flawed, rather it was a decision made by the DPRM model developer in developing a prototype to *test and demonstrate* the applicability of the methodology.

be objective and verifiable- The system developed was objective in that deployment process was closely modelled. System dynamics is capable of developing objective and verifiable models… the more complicated the model, the harder it is to verify. It is always a temptation to create comprehensive models because detailed data to support such (high resolution) models is often easier to find than aggregated data, which may incorporate some degree of subjectivity.

reveal the robustness of posture across scenarios with varying and somewhat unpredictable condition within scenarios- One could test the modelling approach against various scenarios. One of the advantages of computer simulation… is that unpredictable and counter-intuitive conditions can be readily taken into account.

provide useful feedback to the providers of the elemental data- The process employed, and the modelling tools, allow quick feedback to senior officers who contributed... The nature of this feedback ensures that senior officers have confidence in the way the model represents their area of expertise… The feedback provided to the sources of this data is useful in that they can see how their efforts fit into the preparedness levels of their units.

permit comparisons of status from one year to another- An advantage of the system dynamics approach is that predictions on current data and procedures can be examined from one year to the next… [the modelling] was particularly strong in this regard allowing for future events, such as known exercise schedules, to be incorporated so that the variation of preparedness levels could be calculated.

reflect the transition from peacetime to wartime- The methodology allows all steps required to transition a force from peacetime to wartime to be addressed, including often hard to quantify factors such as collective training activities. System dynamics not only

> handles the transition from peacetime to wartime in a logical manner, but also allows flow on effects. If, during a work-up, a particular piece of equipment is used extensively, then the demand for spare parts and maintenance correspondingly increases.
>
> *permit the evaluation of trade-offs*- The [system dynamics modelling] was designed so that trade-off studies could be achieved within a combat capability. Only one combat capability was fully investigated (Air Defence) during the development of DPRM. The methodology does not pose any difficulties for addressing trade-offs and 'what if' analysis (Brunskill and Cox, 1999: 13-14).

Overall, the system dynamics models were assessed as valid and potentially providing a good basis upon which to examine resource / preparedness trade-offs (Brunskill and Cox, 1999: 14). The modelling effort contributed significantly to the understanding of this complex area, albeit the understanding was confined to those closest to the DPRM Project. In mid-1999, the project was closed without achieving the objective stated at 10.5.

10.10 Revisiting Defence Preparedness Problem Conceptualisation

In the first quarter of 1998, over a year before the project was closed, UNSW, aware of conceptual difficulties confronting the DPRM project, offered to provide cognitive mapping analysis to help in revealing the underlying nature of the preparedness problem. The cognitive mapping exercise, which was explicitly identified as a research task conducted by the author of this thesis, quite distinct from the DPRM contract, offered to provide insights into the nature of a range of preparedness issues.

The objectives of the research were to address the very questions which, in the UNSW recommended modelling methodology, should have been addressed at the outset. It should be noted that whilst this case application is the last discussed in this thesis, it was conducted during the early stages of the development of IISD. In effect this was an early action research application of IISD, but one which did not proceed beyond problem conceptualisation and problem definition.

Cognitive mapping sought to shed light on the most vexing questions confronting the ADO executive, financial planners, force element and force element group commanders: *What factors affect cost of achieving extant levels of preparedness? What factors affect cost of achieving future desired levels of preparedness? What are the elements of cost involved in having a Brigade group prepared 28 days from today's date to undertake an amphibious lodgement 500 km from its home base? What is* *involved in raising this force from PLOC to a fully operational level in, say, three months? What factors might preclude achieving a specified level of preparedness?*

10.11 Cognitive Mapping Methodology Applied to Preparedness

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. Also, the more training that is done, the more quickly the equipment life and materiel stocks are depleted, consequently impacting on available operational reserves. These systemic relationships were introduced at Figure 10-5.

Cognitive mapping proceeded in parallel with DPRM system dynamics modelling from June to December 1998. The process involved sequences of two 1-hour structured interviews with the following stakeholders:

a. Colonel David Hurley, Director Preparedness Management.

b. Colonel Paul Power, Director Preparedness - Army

c. Group Captain Brett Biddington - Director Operational Information Systems Development

d. Mr Joe Roach, Director Strategic Resources and Capability Planning

e. Lieutenant Colonel Greg Molyneux, Deputy Director Preparedness Management.

f. Lieutenant Colonel Murray Davies, Deputy Director Preparedness - Army

g. Dr Mike Jarvis, Principal Research Scientist - Special Projects (PRS-SP), Defence Science and Technology Organisation

h. Commander Mike Brown, Deputy Director Preparedness Concepts - Navy

i. Mr Peter Ralston, Project Manger DPRM

j. Squadron Leader Peter McLennan, Deputy Director Preparedness Concepts - Air Force

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 individual debriefing sessions to confirm that the respondents' views had been properly captured. In selected cases a subsequent set of interviews was undertaken after several months. The insights from all interviews were fed back to the individual interviewees and, in summarised form, to the Working Group. The system dynamics modelling consultant was also briefed. The cognitive mapping process revealed the complexity of the project, and significantly different 'mental models' regarding:

a. what Preparedness was,

b. how Preparedness should be managed, and

c. the role that the DPRM might play in the strategic decision-making process.

Director Preparedness Management's early vision of DPRM is depicted at Figure 10-8.

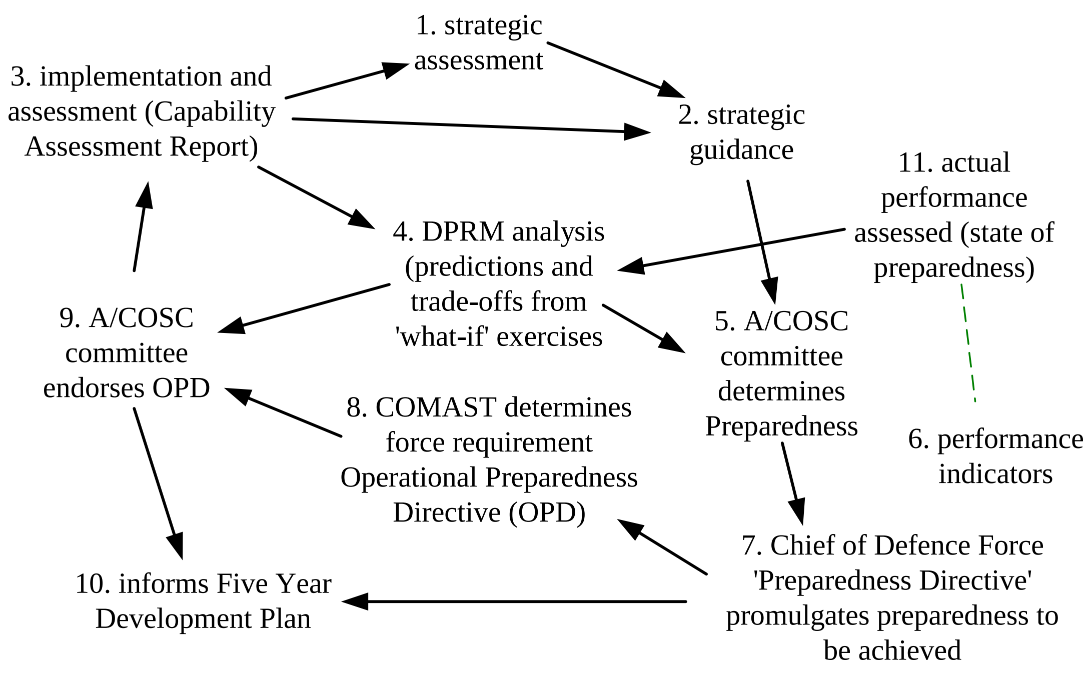


Figure 10-8. Perception of End Product of Modelling

As DPM first expressed it, his cognitive map contained fewer than 20 concepts, noting that at time of interview DPM had been in his new appointment a few months. When he was interviewed several months later, this had grown and changed dramatically, indicating a paradigm shift in his understanding. This growth was attributed to more than greater familiarity with the topic, including:

a. dialogue and discussion fostered by analysis of cognitive maps, both with the author of this research and his Deputy, LTCOL Greg Molyneux;

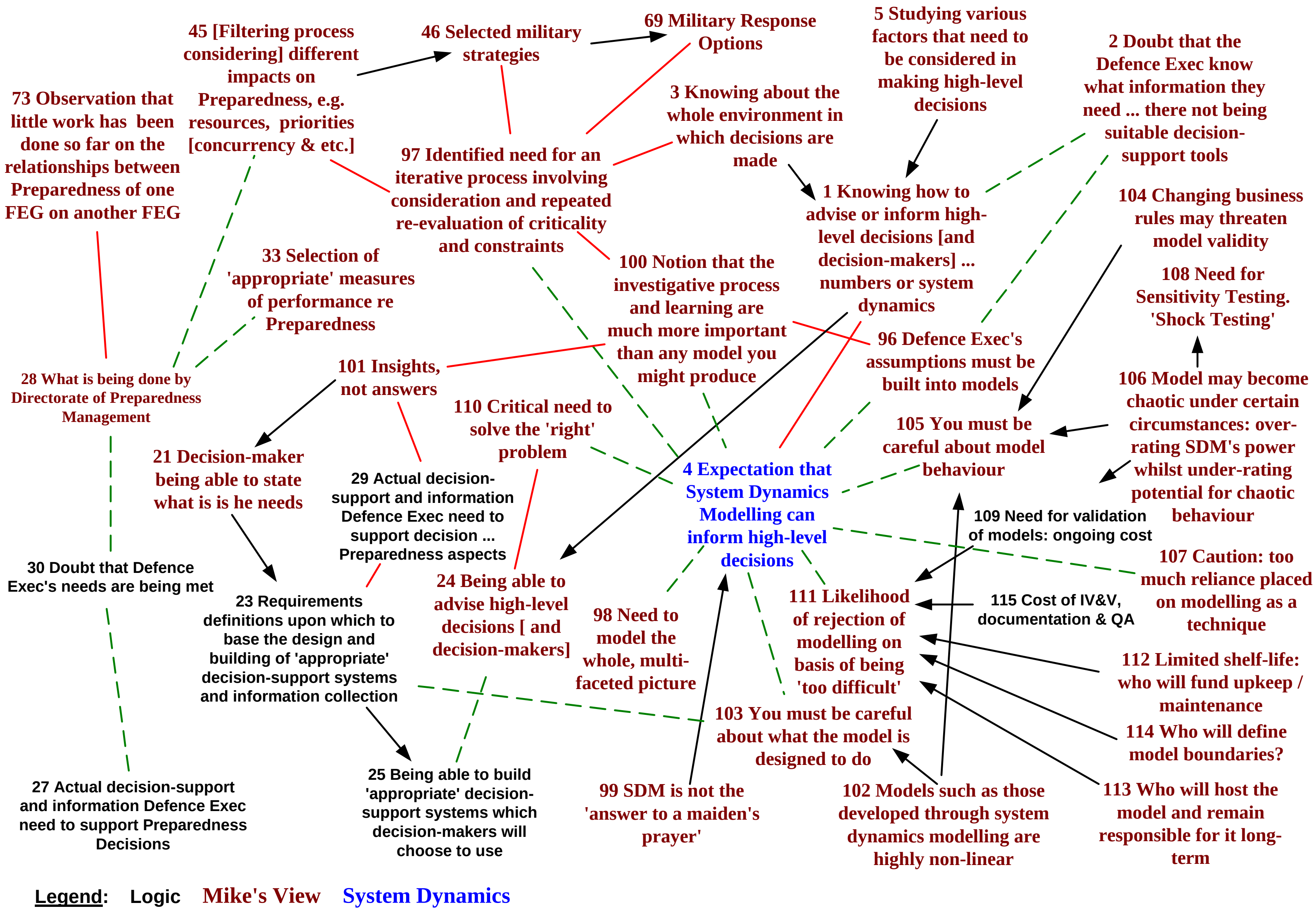
b. frequent briefings on systems thinking and systems concepts;

c. concurrent involvement in the development of ADFP4, the document which formalised the Preparedness management processes; and

d. critical thinking associated with his role in overseeing the development of system dynamics models.

Unfortunately, the cognitive map produced from the subsequent interview with DPM contains sensitive Defence information, which could not be published. An example of a similarly comprehensive map is that of PRS-SP, which is depicted, Figure 10-9. The complete map is at Annex E.

Figure 10-9 Cognitive Map of Preparedness (One of 12 pages) (following page)



73 Observation that little work has been done so far on the relationships between Preparedness of one FEG on another FEG
45 [Filtering process considering] different impacts on Preparedness, e.g. resources, priorities [concurrency & etc.]
46 Selected military strategies
69 Military Response Options
5 Studying various factors that need to be considered in making high-level decisions
2 Doubt that the Defence Exec know what information they need ... there not being suitable decision-support tools
3 Knowing about the whole environment in which decisions are made
97 Identified need for an iterative process involving consideration and repeated re-evaluation of criticality and constraints
1 Knowing how to advise or inform high-level decisions [and decision-makers] ... numbers or system dynamics
104 Changing business rules may threaten model validity
108 Need for Sensitivity Testing. 'Shock Testing'
33 Selection of 'appropriate' measures of performance re Preparedness
100 Notion that the investigative process and learning are much more important than any model you might produce
96 Defence Exec's assumptions must be built into models
106 Model may become chaotic under certain circumstances: over-rating SDM's power whilst under-rating potential for chaotic behaviour
28 What is being done by Directorate of Preparedness Management
101 Insights, not answers
110 Critical need to solve the 'right' problem
105 You must be careful about model behaviour
21 Decision-maker being able to state what is is he needs
29 Actual decision-support and information Defence Exec need to support decision ... Preparedness aspects
4 Expectation that System Dynamics Modelling can inform high-level decisions
109 Need for validation of models: ongoing cost
30 Doubt that Defence Exec's needs are being met
107 Caution: too much reliance placed on modelling as a technique
24 Being able to advise high-level decisions [and decision-makers]
23 Requirements definitions upon which to base the design and building of 'appropriate' decision-support systems and information collection
98 Need to model the whole, multi-faceted picture
111 Likelihood of rejection of modelling on basis of being 'too difficult'
115 Cost of IV&V, documentation & QA
112 Limited shelf-life: who will fund upkeep / maintenance
103 You must be careful about what the model is designed to do
114 Who will define model boundaries?
27 Actual decision-support and information Defence Exec need to support Preparedness Decisions
25 Being able to build 'appropriate' decision-support systems which decision-makers will choose to use
99 SDM is not the 'answer to a maiden's prayer'
102 Models such as those developed through system dynamics modelling are highly non-linear
113 Who will host the model and remain responsible for it long-term
Legend: Logic Mike's View System Dynamics

10.12 Observations from Cognitive Mapping Analysis

Cognitive maps of the Army, Navy and Air Force representatives differed markedly. These differences were not so evident during Preparedness Working Group deliberations when:

a. Group members would automatically revert to a form of low-level language: cognitive mapping suggests that whilst this comprised terminology in common usage, misunderstandings were frequent, but not obvious to a casual observer.

b. Discussion would ensue with confidence and at levels of aggregation suggesting members had similar mental models: cognitive mapping revealed, that mental models differed significantly; and

c. Members gave an appearance of alignment of values: cognitive mapping suggested otherwise.

A few Preparedness Working Group members were unwilling their views revealed by the cognitive mapping process, repeatedly making themselves unavailable to be interviewed. It is considered highly significant that none of those who publicly advocated activity-based accounting as the basis for managing Defence Preparedness made themselves available for interview. They opted instead to provide a formal briefing on the Activity Based Management system they were developing.

The consultant undertaking the quantitative system dynamics modelling was briefed on the results of the cognitive mapping process. The opportunities he had to incorporate the findings of mapping into his modelling were strictly limited by the DPRM Project Manager. The project, once initiated, continued its momentum even though the qualitative analysis was raising significant questions regarding understanding of the objectives of the DPRM Project and its rationale.

There is no doubt, however, that the cognitive mapping and knowledge elicitation processes, in tandem with the quantitative modelling, helped the Working Group to a much better understanding. Over time, DPM developed a strong commitment to the modelling as a process to facilitate learning. His views are summarised in the following cognitive map, developed as a result of a subsequent interview some 12 months after his first involvement with DPRM. See Figure 10-10.

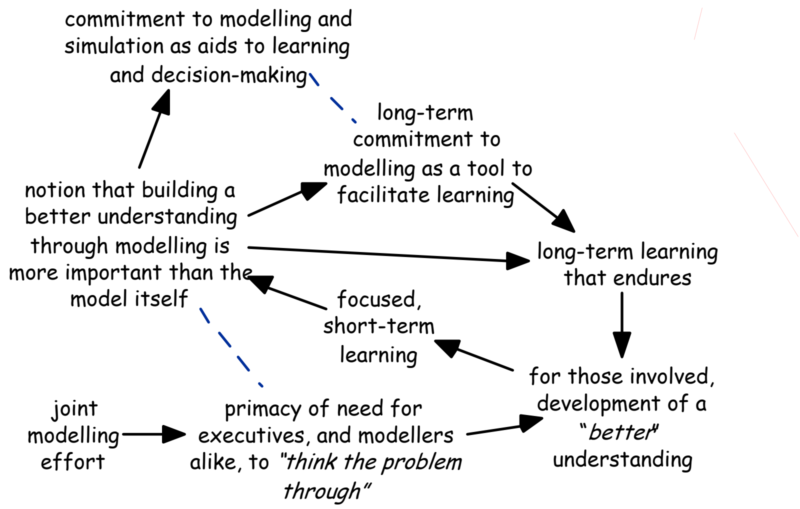


Figure 10-10. Evolving Perception of Modelling to Facilitate Learning

10.13 Defining 'Success' in Relation to System Dynamics Projects

If the criterion for success is that the required decision support system is built and used by the client, then the DPRM project failed. In September 2000, Air Vice Marshall Peter Criss and his Preparedness management staff were briefed on the findings of this research. Their response to the assessment that the project failed was:

> The DPRM project was far from a failure. An enormous amount was learnt by all involved, and, specifically, the Air Defence model worked well and achieved the aims set for it. Obtaining the necessary data from the FE/FEG, and therefore populating the model/s, was a major difficulty, and one of the principal reasons why the project was brought to a close.
>
> There were several sets of 'questions to be answered' developed; the difficulty was, and remains, to know whether the correct questions were/are being asked…
>
> There was a detailed Statement of User Requirement. The problem was that it quickly became outdated, and it was impractical to continually try to update it.
>
> DPRM was only ever intended to be a fact finding project in the first instance… A key aim of the project was to establish whether it was worthwhile to expend a significant amount… to tackle the problem of preparedness management in that sort of manner, using System Dynamics modelling. In the end, the decision was made that System Dynamics was not the way to proceed at that stage, and very little money was spent to make that very important decision. In fact I would argue that so much knowledge/intellectual capital was gained through the DPRM experience, that we in

> Defence are now able to tackle the problem of preparedness management… with a much greater degree of understanding and confidence (LTCOL Molyneux, 6 Oct 2000 - on behalf of AVM Criss).

10.14 Summary - Chapter 10

In this chapter the application of system dynamics modelling and, later, cognitive mapping to the DPRM project were considered. DPRM was conceived to provide decision-support to the highly complex task of managing Defence Preparedness. The DPRM project failed when measured using implementation as the success criterion.

However, despite poor project management and an undeclared contest between alternate techniques (system dynamics and Activity Based Management) for supporting Preparedness decision-making, DPRM was seen as a highly successful learning experience. System dynamics modelling was found to be instrumental in raising awareness of the dynamics of managing Defence Preparedness. Cognitive mapping was found to be an important aid to revealing the nature of issues at hand.

Difficulties in obtaining the data needed to populate system dynamics models proved to be a major force militating against success. Understanding the problem to be addressed proved problematic in itself. It is suggested that this could have been overcome by early and substantial efforts directed at 'finding out about the problem situation' and problem conceptualisation.

There are many factors affecting the successful completion of change interventions, whether they involve modelling or not. Many are inherent in organisations, in organisational cultures, and in the ways individuals view complex, dynamic problems. It is important to determine what is the 'right' problem to be addressed, then managing the allocation of resources and effort to addressing that problem.

10.15 Significant Contributions Made in Chapter 10

This chapter discusses the genesis, execution and lessons learnt from the application of system dynamics modelling and cognitive mapping to a complex problem. It is significant that reasons for successes and failures are addressed so that experiential learning may occur. Those lessons are seen as significant contributions, noting the paucity of such lessons in the literature:

a. A comprehensive understanding of the problem at hand must be developed before proceeding further.

b. Models, particularly ones built at high levels of aggregation, often need to be populated with data not readily extracted from existing data sources. Lack of readily available data should not lead automatically to the rejection of such models. Instead early problem conceptualisation should help identify which data sets may be needed to populate models. This is further discussed at Chapter 11.

c. There are many pressures on modellers to depart from proper modelling procedures. These must be recognised and managed.

d. Rigorous processes for problem analysis, such as those described at Chapters 6 and 7, must be followed. If these cannot be done then a recommendation must be made to abandon the project.

e. Utility of cognitive mapping and system dynamics techniques was reinforced.

f. Effective learning comes about when qualitative and quantitative techniques are used in combination, focusing attention appropriately at different stages in the modelling project.

g. Launching directly into quantitative modelling without first using qualitative modelling in problem conceptualisation is problematic. Integration of the two is considered essential, and should follow a sequence such as described at Chapters 6 and 7.

CHAPTER 11: INVESTIGATING STRATEGIES FOR CORRECTING WICKED PROBLEMS – THE SYSTEM DYNAMICS 'FRONT-END' TOOL

Synopsis

A decision-support tool for conducting first-pass analysis of systemic, dynamic problems is described and demonstrated. The need for such a tool was identified during the conduct of research described in this dissertation. The tool is intended to bridge the gap between influence, or causal loop, diagramming and quantitative system dynamics modelling. It is designed to enable analysis of effects produced by combinations of causes.

Cause and effect relationships are depicted using simple graphics. Frequent changes in the graphical depictions, which are needed as 'what if' analysis proceeds, are enabled through an easy-to-use graphical user interface (GUI). Additive fuzzy arithmetic complements the design of the GUI and is used to compute the combining of causal influences.

Prior to the development of this tool, the depictions of cause and effect were limited to fixed weightings, that is, linear relationships. The recent work of Kim (2000), and Kwahk and Kim (1999), which accommodated only linear causal relationships has been taken a most significant step forward with the development of this tool. Systemic problems containing a wide range of continuous causal relationships can be analysed with relative ease. Relationships may be linear, sigmoid, exponential, hyperbolic, or polynomial with multiple extrema. The significant constraints of depicting causal linkages as '+' or '-', 's' or 'o', or simply as increasing or decreasing in their causal influence, or as simple linear relationships, have been overcome. The product is a powerful tool for supporting action research and action learning through IISD.

This chapter describes a tool [1]which, when used in an IISD context, is expected to enhance understanding of managers about system dynamics, through:

a. exploiting knowledge of domain experts who may be available for a limited time, such as during meetings or workshops conducted for the purpose of addressing a particular wicked problem;

b. providing a vehicle for fostering dialogue, discourse and critical analysis;

c. surfacing and testing assumptions that various stakeholders might have;

d. rapidly building an understanding of dynamic behaviour underlying current difficulties, or which may impact on the development of business strategies;

e. enabling first pass analysis of dynamics when time may not be available to build quantitative system dynamics models;

f. determining whether more detailed analysis through system dynamics modelling and simulation, is needed;

g. undertaking preliminary analysis as the basis for creating a business case for the commitment of significant resources; and

h. rapid prototyping and first pass testing, in a limited time-frame, of a set of strategies for urgent implementation.

11.1 A Tool for Analysis of Dynamic Risks

This tool also offers the facility to analyse the potential impact of a number of dynamic risks. Conventional risk analysis does not address dynamic risks, and does not address the combined impact of a number of risks, except in a rudimentary way. Normally such analysis takes the form of creating scenarios that build on possible, serial, sequences of events. Risks are generally considered on the basis that probabilities are conditional. The outcome of this assumption is that overall risk is calculated by the multiplication of probabilities. Multiplication leads to very small probabilities, with the likely determination, within the context of a given scenario, that risks are insignificant. Conventional wisdom does not cater for changes in likelihood over time, as might come

[1] The SD ‘Front End’ Tool described in this chapter is the subject of an Australian Innovation Patent.

about in a feedback situation or where there is high correlation of risks, as occurs in tightly coupled feedback environments. This tool enables the analysis of risks in such situations. Analysis of dynamic risks does not conflict with the methodology described in AS/NZ Standard 4360: Risk Management. It does, however, extend risk management into new territory.

11.2 Overview of the Utility of SD 'Front End' Tool

Imagine a group modelling workshop starts at 8:35am. A number of domain experts have been assembled to help develop a remedial strategy it is hoped will overcome a vexing problem, one that simply refuses to go away. After 90 minutes of frenetic discussion and debate, flip charts and whiteboards are covered in fragmented causal loop diagrams, focusing on the various component parts of the problem. After a further 35 minutes, or so, a single, complete causal loop diagram of this wicked problem has been created. It is now 10:45am. Several of the team are booked to leave on mid-afternoon flights, meaning that the time available effectively expires when a late lunch is served. In the next two and one-half hours a strategy will be created, and tested through simulation and sensitivity analysis. This seems to be an impossible task. This is exactly the situation many executive decision-makers frequently face.

A prototype of a decision-support tool which offers the prospect of enabling the creation and testing of the strategies the group seeks, has been developed. How it works is explained below. The prototype tool is demonstrated step-by-step. A particularly wicked problem is addressed and a set of coordinated strategies are developed and tested.

How the tool works is explained and calculations are demonstrated using Excel™ spreadsheets. Whilst the prototype tool is somewhat labour intensive to use, in its mature form it will be coded in C++ or Java, and will have an intuitive and easy to use graphical user interface. Significant effort is still required to develop the tool to a marketable product.

Before lunch the assembled team will now be able to:

a. make a series of estimates which describe the current, initial, state of the problem;

b. assign state estimates to the causal loop diagram;

c. estimate the shape and form of the causal relationships which link the various parts of the causal loop diagram;

d. test how well the state estimates, and estimates of causal relationships, fit together in the context of the whole diagram, adjusting those estimates where necessary;

e. run a series of simple simulations which facilitate identification of pressure points, sensitivity to changes in various state estimates or causal linkages, or corrections to the logical structure of the diagram;

f. develop a set of remedial strategies to correct the problem;

g. run simulations to test the efficacy of strategies proposed by the group; and

h. based on what has been learnt about dynamic behaviour of the problem, decide on which strategies to implement.

The SD ‘Front End’ tool has evolved from understandings of systemic structure and system dynamics derived, in large part, from case studies in this dissertation. It is designed as an integral part of IISD. It fosters action learning generally, and the idealised learning loops described at 6.22, specifically. The SD ‘Front End’ tool now makes it both possible and practical to develop strategies for remedying wicked problems without necessarily resorting to quantitative system dynamics. Where it becomes necessary to build quantitative system dynamics models, the choice to do so is better informed by preliminary analysis supported by the SD ‘Front End’ tool and the analytical method described in this chapter.

11.3 Reliance on Causal Loop Diagrams in System Dynamics Practice

Current system dynamics practice involves building causal loop diagrams as primary aids to problem conceptualisation and preliminary analysis of dynamic, systemic problems. Causal loop diagrams are generally interpreted with reference to observed modes of behaviour. Despite known limitations of causal loop diagramming, described by Richardson (1976; 1985), causal loop diagramming is very widely used. As an indication of the extent of this reliance on causal loop diagramming, Sterman (2000) uses some 123 diagrams that are either causal loop diagrams or have the attributes of causal loop or influence diagrams, to demonstrate how to go about problem conceptualisation or causal analysis. The system thinking publications of Senge (1990), Senge *et al*. (1994), Kim (various) promote analysis based on causal loop diagrams as the main pillar.

Often, causal loop diagram construction relies on a great deal already being known about the problem at hand. If knowledge is limited or understanding is superficial, there can be significant risks to building meaningful diagrams.

11.4 Using Causal Loop Diagrams to Help Find Out About a 'Problem Situation'

Particularly in the early stages of finding out about a problem situation, or when system dynamics experience is limited, hypotheses need to be formulated and tested in ways that quickly get to the core of the problem. The tool described in this chapter facilitates action learning through an iterative process of building and then testing hypotheses about what has been observed. See IISD, Chapter 6, and its application, Chapter 7.

As more is discovered about the problem, data collection activities can be directed towards obtaining specific data. The development of the tool described in this chapter offers the unprecedented opportunity to use causal loop diagramming to support *ab initio* investigation of a problem. Unlike other problem conceptualisation techniques which analyse causality in subjective and intuitive ways, the technique described in this chapter goes beyond simply achieving consensus about the causality suggested by the diagram, it actually tests the hypotheses involved. It also seriously challenges mental models of those who proffer that a given causal loop diagram describes the structure and causality underlying a given problem situation.

11.5 Overcoming Limitations of Previous Attempts to Quantify Cognitive Maps and Causal Loop Diagrams

To date, quantification of cognitive maps or causal loop diagrams has been limited to assigning simple polarity and strength of influence to the causal links. Strength of influence has been assigned as weightings, which are no more than simple linear relationships between cause and effect (Kim, 2000; Kosko, 1993: 1997; and Kwahk and Kim 1999). Whilst reasons for limiting relationships to linear ones are not clearly enunciated in the literature, the following reasons are suggested:

a. difficulty associated with setting initial values, particularly when causal linkages are non-linear;

b. calculating a polynomial fit of a curve to available data involves significant computational effort;

c. confidence in curve fitting depends on how comprehensive the collected data sets are;

d. curves fitted to sparse data can be imprecise, and

e. conventional algebra provides limited opportunity to influence the fit of a particular curve through application of additional user defined rules such as … “the curve is asymptotic to a line $y = ax + b$ for values of y above y_1 ”.

Setting up the rules for computation and creating the supporting algebra are time consuming activities which militate against achieving desired outcomes from group modelling workshops. An inordinate amount of time can be consumed by such activities. SD ‘Front End’ tool is designed to minimise time consumed by these activities.

In the conventional system dynamics methodology, causal loop diagramming leads to the creation of general conclusions about problem structure and systemic behaviour. This leads into the development of quantified system dynamics models, though the logical development from one to the other is problematic unless rigorous rules for defining and sequencing flows and stocks are followed, as in Coyle’s influence diagramming method. As was found in the DPRM modelling project, in Chapter 10, proceeding prematurely to building system dynamics models can be counterproductive. Equally, spending inordinate time and effort in problem conceptualisation can mean that remedial strategies for wicked problems are never formulated.

11.6 Getting Started More Quickly

The tool and techniques described here enable problem conceptualisation, extensive qualitative analysis and limited quantitative analysis. An outcome of the use of this tool, techniques and IISD are expected to be better understanding of scope and objectives for subsequent quantitative system dynamics modelling and simulation. Preliminary analysis also helps reveal just which data sets need to be collected.

Collection of data can commence even before the preliminary analysis is completed. This is important because data collection can be the rate determining activity. Given that the required data can be collected concurrent with the early stages of model building, products from quantitative modelling can flow more quickly.

This tool offers the opportunity to undertake the following:

a. rapid preliminary analysis of dynamic behaviour, noting that often the opportunity to undertake such analysis might be restricted to a workshop or meeting attended by those with specialist domain knowledge;

b. exploration of changes over time, previously possible only through the building of system dynamics models;

c. identification of pressure points;

d. sensitivity analysis, that is, identification of significant sources of influence and the extent to which, singly or in combination, they produce change; and

c. identification of the causes of shifts in feedback loop dominance.

11.7 Limitations of Prototype Tool

It is not intended that the tool described here be a replacement for conventional system dynamics modelling and simulation. It fills an identified gap between qualitative and quantitative analysis and serves as a precursor, and informant to the design and conduct of, quantitative modelling and simulation activities.

In its current prototype form, the tool described does not have facility to handle delayed causality on a single link, or total delay in a feedback loop. Enhancements, described at 11.29, will overcome these limitations. Enhancements to provide for time-series inputs, such as sinusoidal waves, are not planned on the basis that models requiring this level of sophistication are best built using conventional system dynamics modelling.

The theoretical basis for the SD ‘Front End’ tool is described below.

11.8 Theoretical Basis for SD ‘Front End’ Tool - Fuzzy Systems Analysis

Kosko (1997) explains that fuzzy systems are universal approximators. Their fidelity depends on the number of fuzzy rules used to approximate the functions in which we are interested. Fuzzy function approximation is used here to build the graphical user interface (GUI) for depicting the cause and effect relationships that are fundamental to the development of this SD 'Front End' tool. Fuzzy function approximation is also used for the supporting computations.

The tool is intuitive in its use, quick to apply and easy to use. Its use encourages trial and error, thereby fostering action learning.

A fuzzy system F is a set of if-then rules that maps inputs to outputs. The rules define fuzzy patches in the input-output space $X * Y$. The fuzzy system $F: X \rightarrow Y$ approximates a function $f: X \rightarrow Y$ by covering its graph with rule patches and averaging patches that overlap. The approximation tends to improve as the fuzzy rule patches grow in number and shrink in size as in Figure 11-1. Kosko (1997:42) notes that the rules grow exponentially in number as the dimensions of X and Y grow. The best lone rule patches cover extrema or bumps in the graph of f.

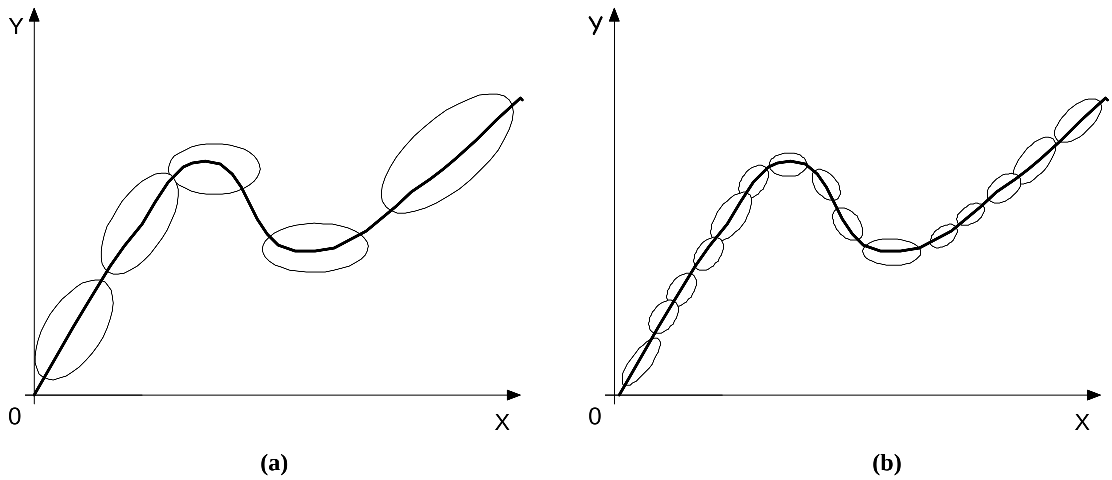


Figure 11-1 Fuzzy Approximation as a Fuzzy Cover (1)(2)

Notes:

1. In Figure 11-1 (a) five large fuzzy rule patches cover part of the graph of the unknown function or approximation $f: X \rightarrow Y$.

2. In Figure 11-1 (b) a larger number of small patches provide better cover of the function f but at greater computational cost. Each rule patch defines a fuzzy subset of the product space $X * Y$. A large but finite number of fuzzy or precise rules can cover the graph and give a fuzzy system F that approximates f with arbitrary accuracy.

11.9 Continuous Functions Only

It is assumed that each function linking cause and effect is continuous.

11.10 Causal Loop Diagrams – Important Tools Despite Their Limitations

Causal loop diagrams are widely used despite their known limitations. In his introduction to Richardson's 1985 paper on the problems of causal loop diagrams, Sterman made the following observations:

> The first system dynamics work did not include the use of causal-loop diagrams. Feedback structure was portrayed by equations or stock-and-flow diagrams. Such representations were natural for engineers. In an attempt to make system dynamics accessible to a wider range of people, causal-loop diagrams have become increasingly popular. In many texts and courses they are the first tool described. Indeed, recently several analysts have proposed that system dynamics studies can be carried out without the development of formal models at all. Causal-loop diagrams often figure prominantly in such analyses. Yet even those who advocate the use of qualitative system dynamics are careful to point out that in all the successful applications of such qualitative methods the analysts have had extensive experience with formal model building. Nevertheless, it seems inevitable that people at all experience levels will continue to rely on causal-loop diagrams. …[Whilst] difficulties arise because causal-loop diagrams obscure the stock and flow structure of systems… [and] even experienced modelers are easily misled by causal-loop diagrams… Despite their problems, causal-loop diagrams are likely to remain important tools for communication of feedback structure (Richardson, 1985: 158).

11.11 Even Experienced Modellers Easily Misled by Causal Loop Diagrams

An important driver for the development of the SD 'Front End' tool is Sterman's statement, in the last few lines above, which recognises that even experienced modellers are easily misled by causal loop diagrams. If experienced modellers are easily misled, then inexperienced ones are at significant risk of making errors of interpretation during problem conceptualisation and preliminary analysis.

It seems most unlikely, though it would be highly beneficial, that causal loop diagrams will ever be replaced in any widespread sense by the more logically robust influence diagrams, such as are advocated by Coyle (1996). A summary of the use of Coyle's influence diagramming can be found at 7.13.

11.12 Bridging the Gap Between Qualitative and Quantitative Analysis

Despite limitations of causal loop diagrams, there is clear evidence as to their continued and growing popularity as a means of analysing, albeit in a superficial way, and communicating ideas about, feedback structure. Unfortunately, causal loop diagrams can hide a litany of potentially erroneous assumptions about the nature of causality. In causal loop diagrams, the only commitment the creator may make to enunciating details about the relationship between cause and effect is the annotation of causal linkages as '+' or '-', 's' or 'o', that is, the relationship is positive or negative in polarity.

If causal loop diagrams can be given greater utility to support the important activities of surfacing and testing assumptions about what underlies the observed reference modes of behaviour, system dynamics practice could be significantly improved. The need for the SD 'Front End' tool derives from concerns raised by Coyle (2000), Ford and Sterman (1998), and Nuthmann (1994). The analytical functionality provided by this tool is unavailable in extant system dynamics applications, which can only graph a change in a parameter over time rather than under the influence of another parameter. The SD 'Front End' tool is expected to prove valuable in facilitating research into how decisions are made and how parametric estimation is done, with a view to improving the quality of both. With this in mind, a deliberate attempt has been made to keep the SD 'Front End' tool as simple as possible to use. Whilst there is a risk of making it too simple, the trade-offs between simplicity and level of confidence which we might have in the analyses we make when we use it, have been carefully made. The use of this tool is demonstrated below by application to analysis of a particularly wicked problem.

11.13 A Particularly Wicked Problem – Availability and Use of Illicit Drugs

The supply and use of illicit drugs creates innumerable, undesirable, side effects for society. These include a drain on medical resources for treatment and rehabilitation, burglaries and a black market in stolen goods. The product of a workshop to consider the ways of managing drug-related issues might look like Figure 11-2:

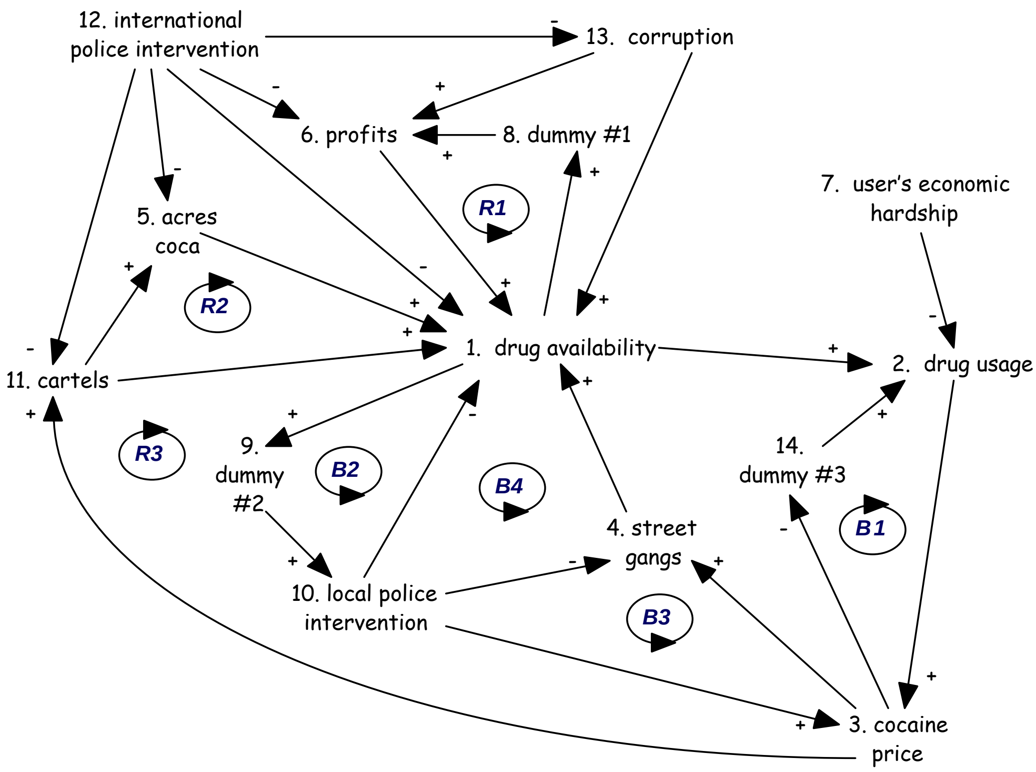


Figure 11-2 Typical Problem: Illicit Drug Usage (1)(2)(3)

Notes:

1. This causal loop diagram is the product of research by Taber (1991: 83-87).

2. Nodes 8, 9, and 14 have been added to remove bi-directional arrows which Taber used in his original version of the diagram. Whilst the diagram appears different as a result of these changes, there is no effect on logical structure.

3. Kim (2000), Kosko (1993; 1997) and Kwahk and Kim (1999) all assume cause and effect relationships are linear. In contrast, non-linear cause and effect relationships are assigned to the illicit drug problem described in this chapter.

11.14 Making Estimates of Causality

Kwahk and Kim (1999) use ‘causal impact’ questionnaires to establish whether the relationship between cause and effect is increasing or decreasing, very strong, strong, or weak. They apply simple weightings as a result. Kosko (1993) uses a similar technique. These approaches are limiting, if for no other reason than they necessarily suggest linear causal relationships. Non-linear relationships are much more likely to occur: this is a persistent observation over nearly 40 years of system dynamics practice.

Consider the following example of the relationship between 1. drug availability and 2. drug usage (usage of illicit drugs by existing users). It is unlikely that hard data about either drug availability or drug usage or the relationship between the two, would exist.

However, educated guesses may be made. The following are likely to be known, or could be established.

a. The number of drug busts affected by police and drug agencies.

b. The quantities of drugs seized during raids.

c. The number of drug overdoses attended by paramedics or handled by hospital emergency medical staff.

d. The number of deaths attributed to drug overdoses.

e. Size of the general population.

f. Estimated size of the drug-using population. For example, 1 in 1,000 of the general population may be estimated to be users of illicit drugs such as cocaine.

The following might be reasonably deduced, or deduced from available information sources:

a. Zero supply equates to zero usage: the 1. drug availabilty / 2. drug usage curve passes through the origin.

b. Even when availability reaches glut proportions, only so many people will use drugs. That is, the curve is asymptotic to a vertical line depicting the estimated maximum size of the drug-using population. This number might be taken as the totality of the estimated population, plus an arbitrary percentage, say 10%, for growth during the period over which this study is to be conducted. In a city of 300,000, it might be estimated that there is a maximum of 330 cocaine users (one in 1,000 plus 10%).

c. It is estimated that the maximum 330 users consume y_1 grams of cocaine per year. Note that we are not interested in absolute numbers, *per se*, but the estimates are needed to enable normalisation of scales on the axes of each graph. Maximum values on each axis are normalised to unity. Rationale behind estimations made and normalisation calculations must be recorded for future reference.

Such reasoning enables the construction of basic relationship diagrams, such as Figure 11-3, below. A scattergram of estimates, combined with known data, might appear as shown.

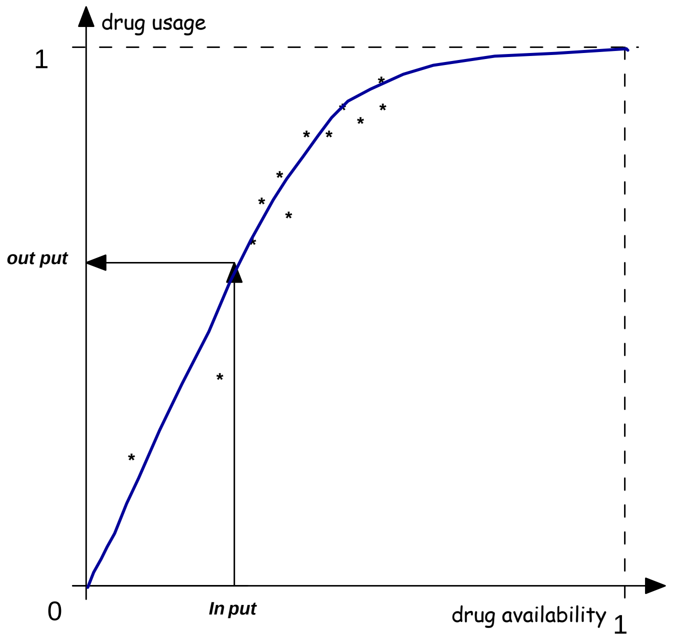


Figure 11-3 Basic Relationship Diagram

From such a graph, we are seeking to determine for each input, what the appropriate output value might be, noting that this may change as a result of each iterative calculation, as occurs when simulating changes over time. Ford and Sterman (1998) describe, then demonstrate the application of a methodology, in a group setting, for aiding experts in the process of explicating their tacit knowledge. This is directly applicable to the process, described above, of estimating and formalising causal relationships for further analysis using the SD ‘Front End’ Tool.

11.15 The General Case – Using Fuzzy Approximators

Experience from fuzzy systems practice (Kosko 1993; 1997) suggest robust fuzzy approximators can be designed around relatively few fuzzy sets. In two-dimensional situations, such as the cause and effect relationships we are considering here, as few as five fuzzy sets may be adequate to establish the cause and effect relationships of interest. The number five is arbitrarily chosen. For convenience, the examples that follow in this chapter will be based around this number of fuzzy sets.

An adaptive fuzzy system has rules in the form… "If input conditions hold, output conditions hold." See Figure 11-4 below. The then-parts of fired if-then rules are added.

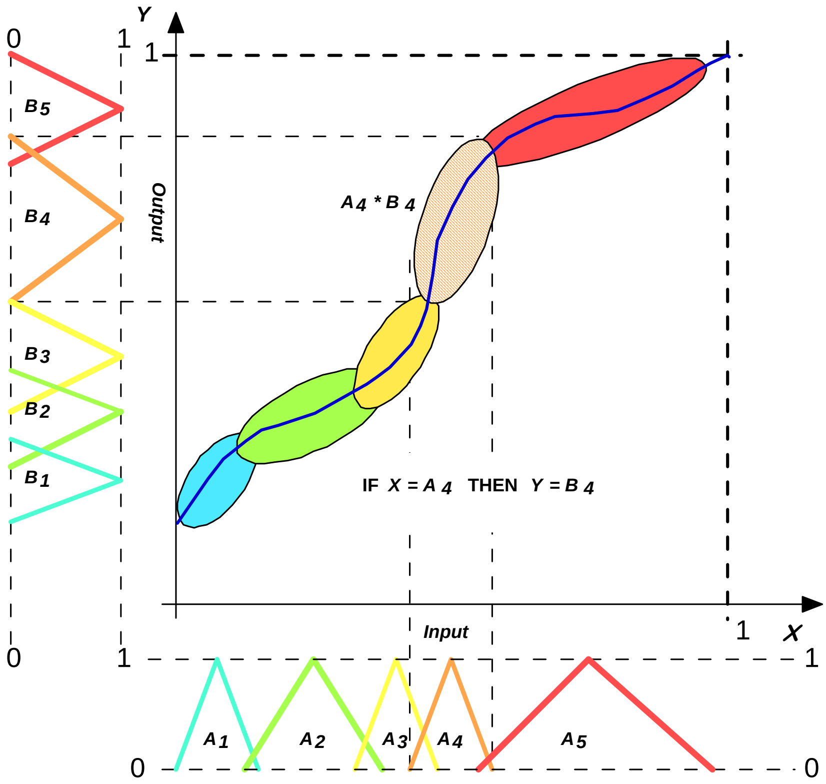


Figure 11-4 General Case –Using Fuzzy Systems (1)

Notes:

1. Adapted from Kosko (1993: 215-221; 1997: 8-11; 43-45; 139-143).

If *X* is *A*, then *Y* is *B* for fuzzy sets *A* and *B*. Each fuzzy rule defines a fuzzy patch or Cartesian product *A***B*. The fuzzy system covers the graph of a function with fuzzy patches and averages fuzzy patches that overlap. Uncertain fuzzy sets give a large fuzzy patch or rule. Small or more certain fuzzy sets give small patches.

11.16 Additive Fuzzy Systems Architecture

The additive fuzzy system architecture (Kosko, 1997: 48) is shown in Figure 11-5, below. The input x_k acts as a delta pulse (or unit bit vector) and fires each rule to some degree. The system adds the scaled output fuzzy sets. The centroid of this combined set gives the output value y_k.

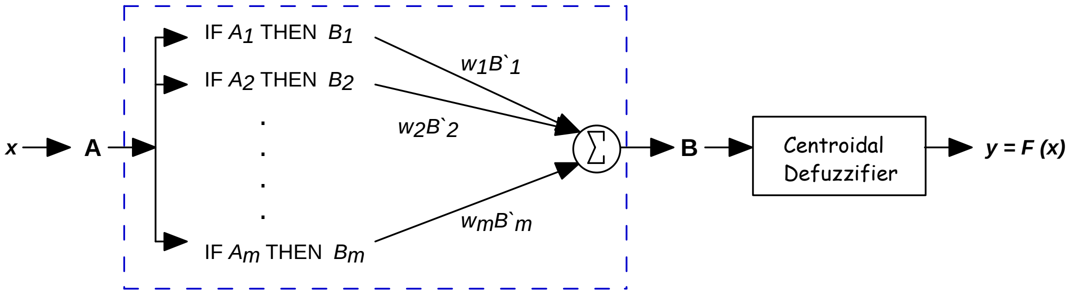


Figure 11-5 Adaptive Fuzzy Systems Architecture - Standard Additive Model

The system computes the conditional expectation value $E[Y|X = x_k]$ as a convex sum of the local centroids or centres of the then-part sets B_j‘. Adaptive fuzzy systems fire all rules in parallel and average the then part sets B_j‘ to get the output fuzzy set B, as in Figure 11-5.

Correlation product inference scales each then-part set B_j by the degree $a_j(x)$ that the rule “IF A_j THEN B_j” fires. Most rules fire to degree 0. Defuzzification of B gives a number or a control signal output. Centroid defuzzification with a correlation product inference gives the output value y or $F(x)$ given the output vector $x \in R^n$.

$$y = F(x) = Centroid\ (B) = \frac{\int y\, b(y)\, dy}{\int b(y)\, dy}$$

$$y = \frac{\sum_{j=1}^{m} w_i\ Volume\ (B'_j)\ Centroid\ (B'_j)}{\sum_{j=1}^{m} w_i\ Volume\ (B'_j)} = \frac{\sum_{j=1}^{m} w_i\, V_j\, a_j(x)\, c_{yj}}{\sum_{j=1}^{m} w_i\, V_j\, a_j(x)}$$

Where V_j is the volume of the j th then-part set Bj and w_j is the weight of the j th rule (often $w_j = 1$). The term c_{yj} is the centroid of the j th output set. Fit value $aj(x)$ scales the then-part set B_j. m is the number of then-part fuzzy sets.

11. 17 Simplifying Conditions

For computational convenience and speed, the following simplifying conditions are created:

$w_j = 1$ Each then-part set is given equal, unity, weight.

$j = 1$ For convenience, the number of then-part sets is assigned the arbitrary value of five (5). If finer computational granularity is required, it is simply a matter of increasing the number of fuzzy patches used to depict the relationship. It is expected j may be increased in the final version of the SD 'Front End' tool, depending on the level of granularity needed in input–output relationships.

In Figure 11-6, generalised fuzzy patches, which normally take the form of ellipsoids, are replaced by rectangles for simplicity and ease of computation.

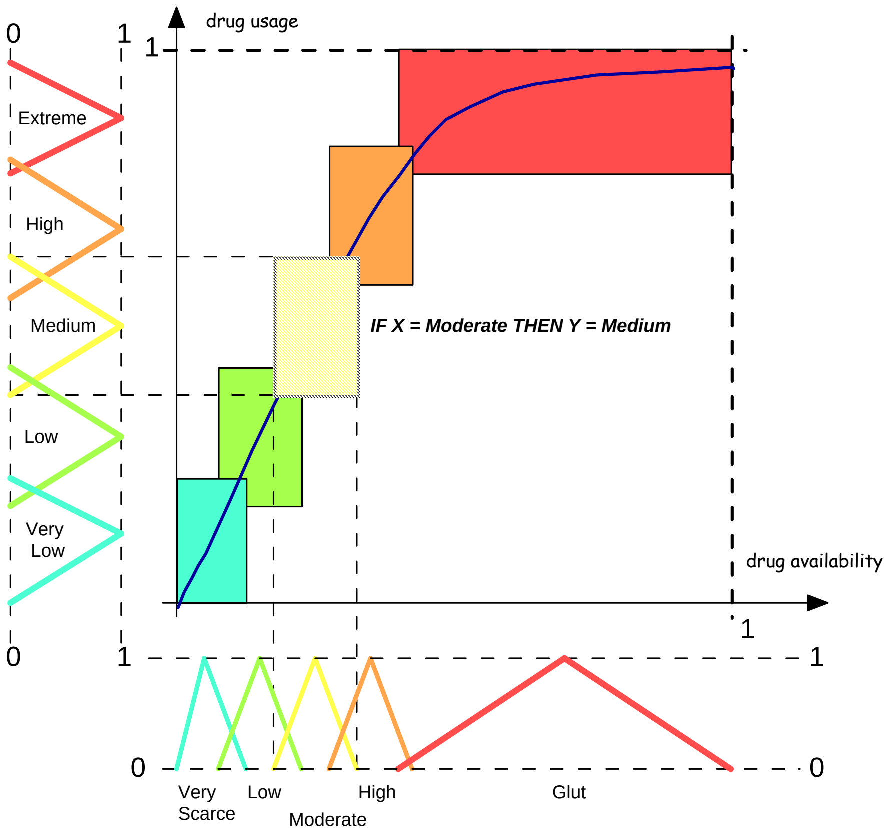


Figure 11-6 'IF Moderate Drug Availability THEN Medium Drug Usage' – Mapped Using Rectangular Fuzzy Patches

Each then-part fuzzy set is connected to the next. That is, they overlap to some extent. It is not necessary for the overlapping fuzzy sets to span the whole range of values on the y axis, provided the output range is continuous and all possible input values are covered.

Additive fuzzy systems average out overlaps, where they occur. It is considered that loss of accuracy resulting from this approximation will be minimal.

11.18 Calculating Outputs Using Fuzzy Additive Arithmetic

The fuzzy system *F* maps an input *x* to an output *F(x)* in three steps. See Figures 11-6 and 11-7.

a. The first step matches the input *x* to all the if-part fuzzy sets (level of drug availability) in parallel. This step "fires" or "activates" the rules by how much the input *x* (drug availability) belongs to each if-part set *A* (level of drug availability). Each input *x* fires at most two rules for the if-part sets in Figure 11-6. As we are using overlapping sets along the input axis, an input *n*-vector *x* fires 2^n rules. Then each fired if-part set *A* scales its then-part set *B* and *B* shrinks down to this height: in Figure 11-7, this is not shown because the maximum summed value is unity.

b. The second step adds all the scaled or shrunken then-parts into a final output set.

c. The third step is "defuzzification". The system computes the output *F(x)* as the centroid or centre of gravity of this final output set. The standard additive model, Figure 11-5, computes the output *F(x)* given the input *x*.

A more detailed explanation of this process is provided by Kosko (1997: 8-12).

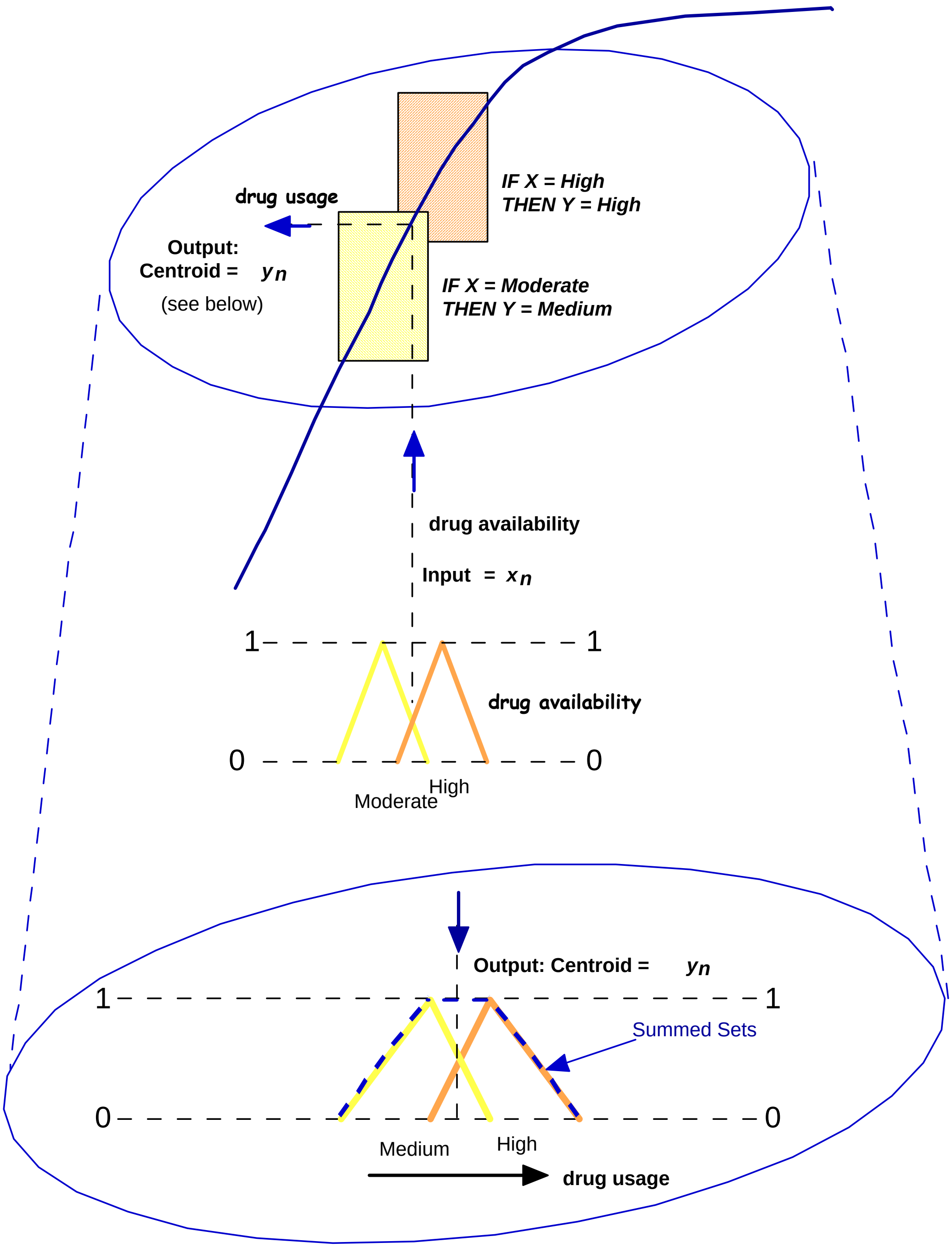


Figure 11-7 Inference in a Fuzzy System

In Figure 11-8, below, inputs in the ranges $x_1 \ldots x_9$, return $y_1 \ldots\ y_9$ respectively.

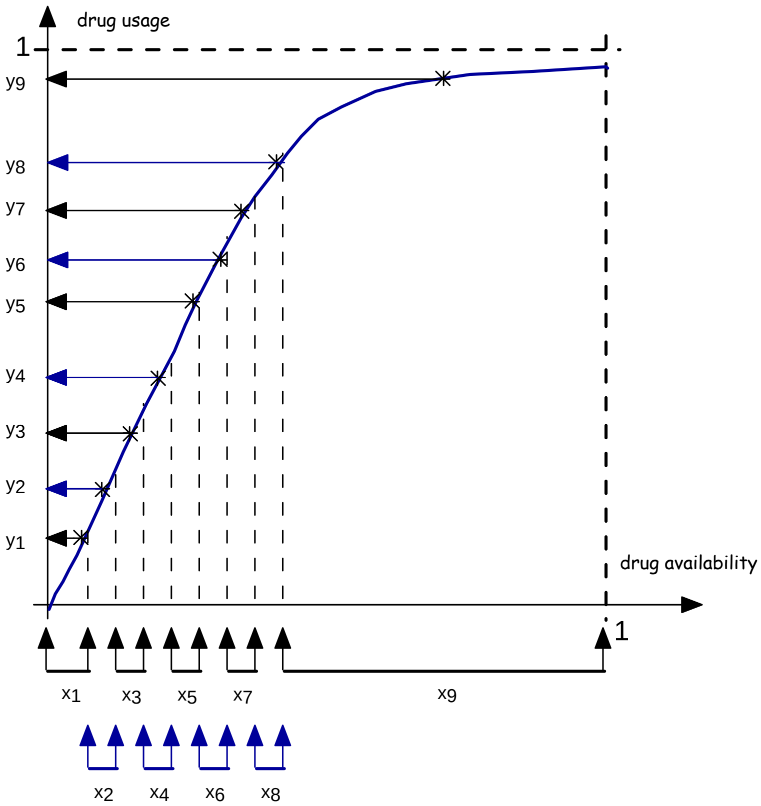


Figure 11-8 Input Ranges x_n and Corresponding Outputs y_n

Even though we have specified only five fuzzy patches, this translates to nine points on the curve. Whilst the values of y_n returned generally do not lie exactly on the curve, do not correspond with the centre of the input ranges, and are not evenly spaced along the input axis, there are a number of distinct advantages of using fuzzy additive arithmetic.

The main advantage is that the curve does not have to be drawn exactly, mainly because its shape is infrequently known with a high level of confidence. Rather, a number of fuzzy patches can be placed over the expected data and the patches made smaller as the level of confidence in the data increases.

In Figure 11-8 we are more concerned with low to mid-range values, than we are at the upper extremity. Definition of the fuzzy patches can be used to advantage by making fuzzy patches smaller where greatest sensitivity is required. So the fuzzy approximation serves our purpose well. Just how well is discussed briefly at the end of this chapter and in the detailed critique in Chapter 12.

11.19 Intialisation of the Causal Loop Diagram – A Critical Step

Initialisation of the diagram is exceedingly important:

a. Estimates made of nodal values are critical determinants of the viability of the diagram. If these estimates are erroneous then initialisation will be difficult to achieve, or it will be meaningless.

b. Careful consideration is needed in the creation of the causal relationship graphs. Suggestions about making estimates of causal relationships are at 11.13. Making such estimates demands considerable rigour and discipline. Insight into how causal relationships produce observed modes of behaviour comes with experience in system dynamics. This is an unfortunate reality for the novice who must take extra care in formulating hypotheses about the shape of the graphs and critically examining how those relationships contribute to the observed behaviour.

c. Concurrent adjustments of estimates of nodal values and shape of causal relationship graphs may be needed. It is essential that adjustments be made through an iterative process. The aim is to create revisions resulting in nodal values and causal relationship curves that are consistent, that is, influences combining to produce the respective nodal state values.

11.20 Initialisation of the Model – Iterative Re-alignment of Estimates Made and Mental Models

As initialisation of the model proceeds, there will be cycles of estimating, validating and adjusting. This will produce change to both the estimates made to initialise the model, and the mental models of those making the estimates. It may be necessary to make changes to the diagram to correct illogical structures. Illogical structures, such as logical omissions or incorrect polarity are frequently detected during initialisation. For discussion of logical omissions from concept maps, also relevant to causal loop diagrams, see 3.5, 3.6 and 4.14.

The process of initialisation can lead to confusion over which adjustments should be made first, adjustments to the estimates of nodal values or the form of causal relationships. Estimates of nodal values should be among the first products of group modelling activities, nominal group technique or Delphi. Achieving agreement about these must be the first priority. Estimating the form of the causal relationships should be a secondary activity. Estimates of the shape of the causal relationships may change numerous times during initialisation, and during the subsequent analysis.

11.21 Setting Initial Values – Making Estimates of Nodal Values

The first step is to establish estimates of the state values at each node. Values are recorded along with explanations of why particular values were chosen. See Table 11-1:

Node No. & Node	Value	Basis of Determining Estimated Value
1. drug availability	0.5	Median value between best and worst observed over the past three years.
2. drug usage	0.6	Based on records of recent treatment of overdoses by hospitals and paramedics.
3. cocaine price	0.7	Based on estimate provided by Police drug squad.
4. street gangs	0.5	Based on estimate provided by Police drug squad.
5. acres coca	0.4	Drug Enforcement Agency (DEA) estimate provided through local Police.
6. profits	0.6	Nominal group estimate.
7. user economic hardship	0.3	Based on estimates provided by Health and Social Security.
8. dummy	0.0	Not applicable.
9. dummy	0.0	Not applicable.
10. local police interdiction	0.4	Local Police activity reports.
11. cartels	0.6	DEA estimate provided through local Police.
12. international police intervention	0.45	Nominal group estimate, supported by DEA reports.
13. corruption	0.3	Nominal group estimate, supported by DEA reports.
14. dummy	0.00	Not applicable.

Table 11-1 Estimated Values at Each Node

These estimates become benchmarks for initialisation of the causal loop diagram. Fundamentally, initialisation is a trial and error activity. The influences from each of the causal relationship curves are summed to produce calculated nodal values. These are compared with the estimates at Table 11-1. The causal relationships for every causal link must be estimated, following the process described at 11.13. These causal relationships appear as at Figure 11-9, below:

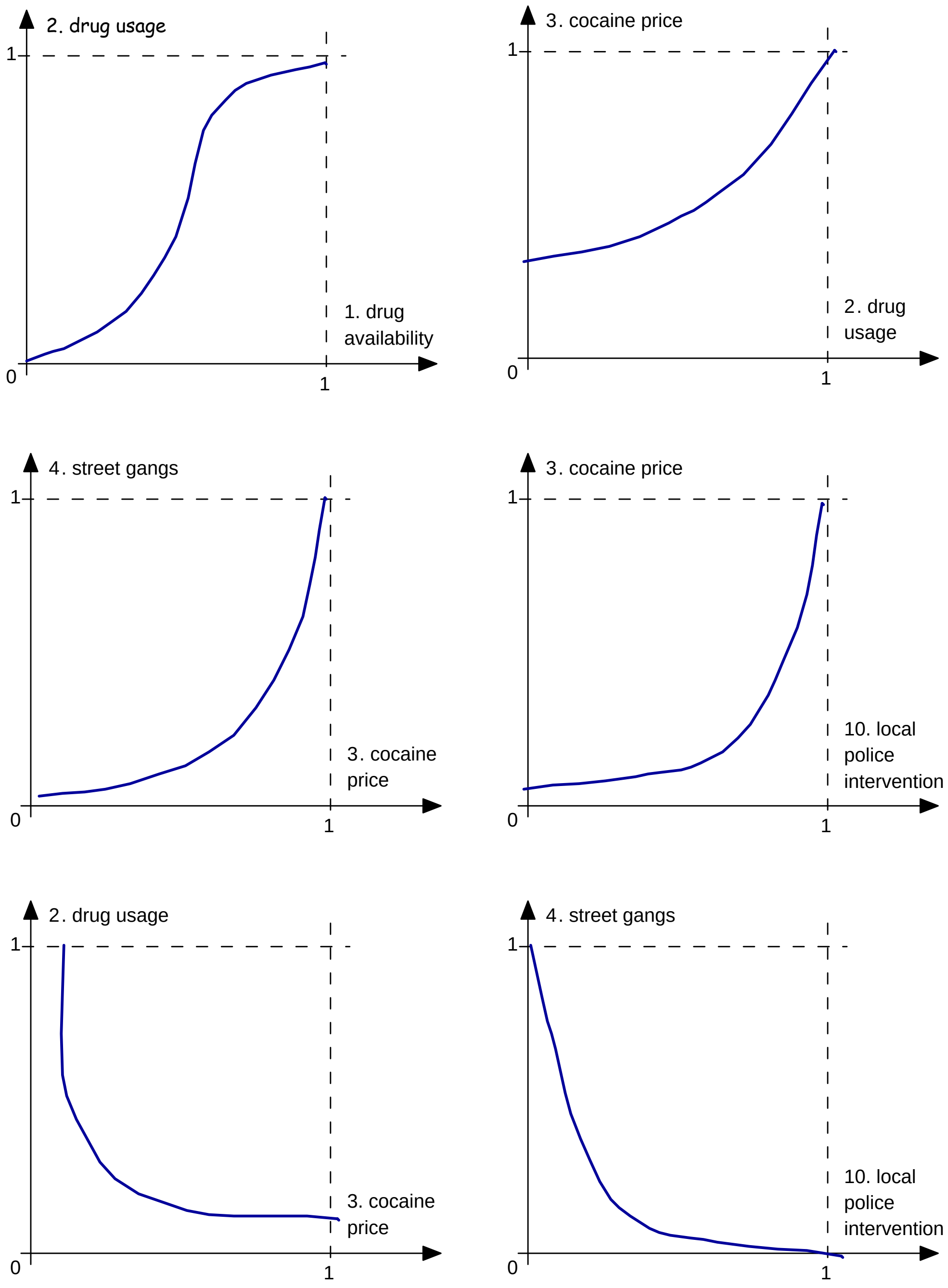


Figure 11-9 Sample Causal Relationship Curves for the Illicit Drug Use Problem

Graphs are drawn using the input device shown at Figure 11-10, below.

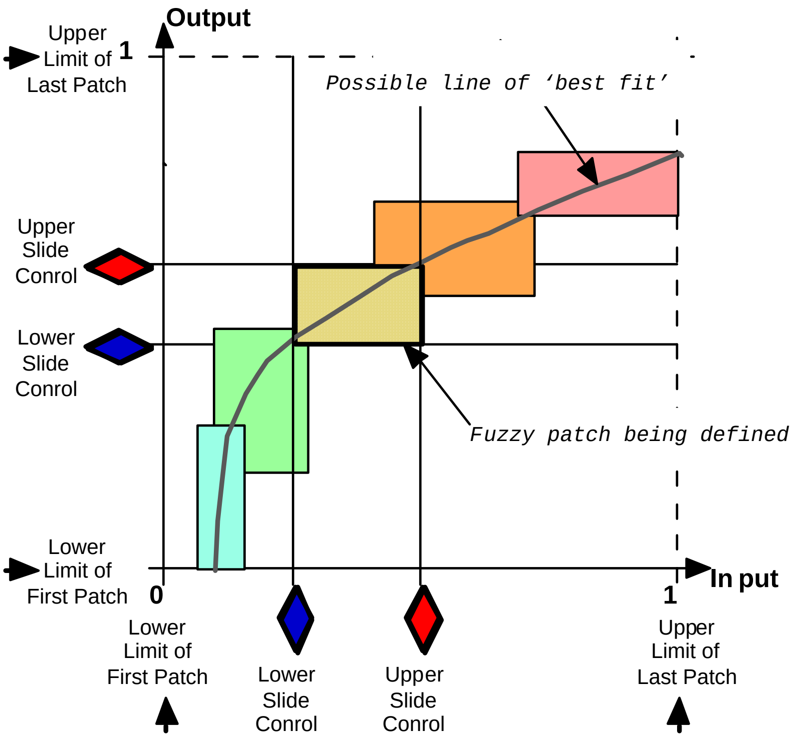


Figure 11-10 Fuzzy Patch Input Device

The fuzzy patches are defined by:

a. Selecting a fuzzy patch.

b. Fixing the lower and upper *x* values of the fuzzy patch by positioning the appropriate slide control.

c. Fixing the lower and upper *y* values of the fuzzy patch by positioning the appropriate slide control.

d. Repeat b. and c. until all fuzzy patches are positioned. Note that in the mature version of the SD 'Front End' tool, fixing the coordinates of the opposite corners of each rectangle may simply be a matter of a mouse click on one corner then the next, until the required number of fuzzy patches are created and positioned. In effect we are approximating a curve by a set of short, overlapping, straight lines and using additive fuzzy arithmetic to calculate the output for each input.

e. Calculations start at the focal node, 1. drug availability, after selecting its initial value from Table 11-1. The sequence of calculations is described at 11.22.

11.22 Discipline Needed in Defining Fuzzy Patches

Defining fuzzy patches is fundamental to creating the necessary causal relationships. Whilst this may be done in real time, such as during a workshop, defining causal relationships requires considerable discipline. In the absence of hard data, employing a nominal group, as described in 7.4, questionnaires as used by Kwahk and Kim (1999) or workbooks used by Vennix (1996: 114) in group model building, are suggested as alternatives for producing reliable estimates. The veracity of estimates is determined by experience of the group members, and their understanding of what underlies causality.

Rather than simply locate individual patches on the basis of judgement and intuition, it is necessary to explain, then record the rationale behind the selection of size, shape and relative location of every fuzzy patch. In the Illicit Drugs example, there are 23 causal relationships, each containing five fuzzy patches, a total of 115. The location of each patch is important to the definition of each causal relationship: the influences produced by these causal relationships must combine at the node to produce the values estimated at Table 11-1. If they do not, each estimated nodal value and each causal relationship must be critically analysed. Only when the inputs to each node sum to the estimated values, can the calculations be made for each loop in the diagram. The sequence of calculations is described at 11.23.

11.23 Creating Correct Sequence of Calculations

The original causal loop diagram, Figure 11-2 is prepared showing only the nodal identifier numbers and the various feedback loops. Polarity is shown as '+' or '-' as appropriate, and only used as a reminder of the general shape of the curve. All inputs to a node are added: polarity does <u>not</u> suggest addition or subtraction of influence at the node concerned. In the absence of a sign, polarity is assumed to be positive. The *assumption that influences at a node are additive* will be discussed further at Chapter 12. The re-drawn causal loop diagram is at Figure 11-9, below:

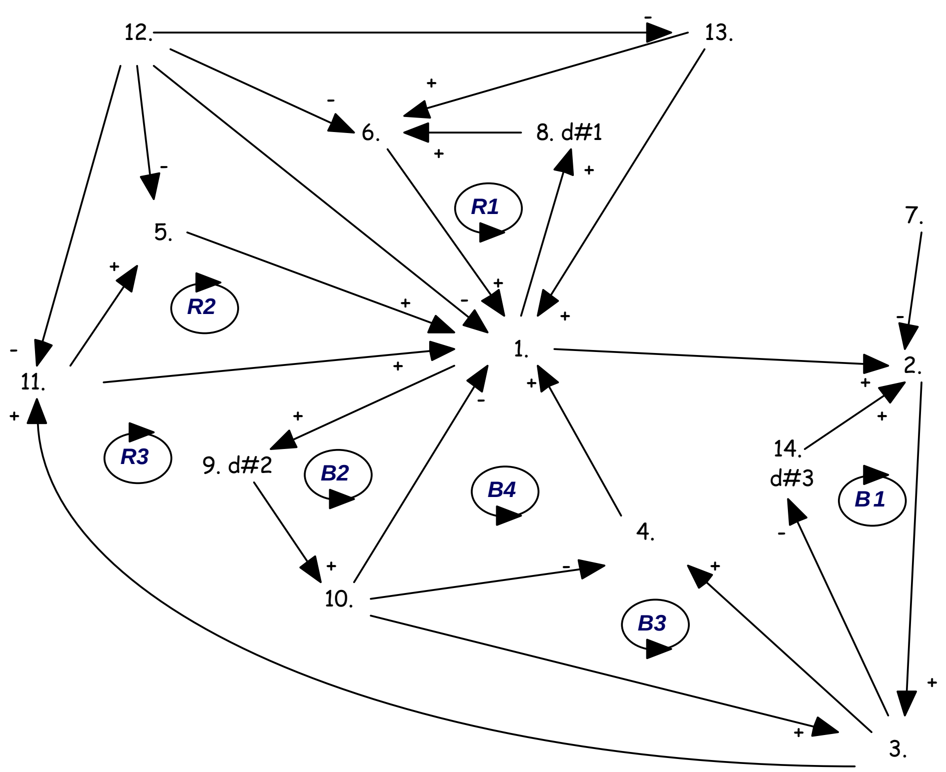


Figure 11-9 Drugs Causal Loop Diagram Showing IDs and Feedback Loops

Where feedback loops are involved, the order in which calculations are made is critical:

a. A focal node is selected. This node becomes the start and finish for each cycle of calculations. We might also consider selecting this node on the basis of its importance as an indicator of the effectiveness of any strategy we might develop. In this case, the focal node chosen is 1. drug availability. Any node can be the focal node. Whilst points of interest may change during analysis, the focal node remains as initially defined. However, a specific node is nominated to ensure the logic of setting up the order of calculation is correctly established and maintained, noting that the products of one cycle of calculations will need to be stored and used as the starting values for the next iteration.

b. Identify the longest feedback path, that is, identify the longest (or equal longest) path which leads back to the start. It must be possible to track from beginning to end of this path without traversing any link more than once. If there is an equally long path, from this point on, it is treated as a subordinate feedback loop.

A clockwise convention is followed for the main (longest) loop. This may require the diagram be re-drawn. Redrawing of subordinate loops is a matter of personal choice. If those loops are short, redrawing should be unnecessary. The longest feedback loop is as depicted at Figure 11-10, with only the direct inputs shown.

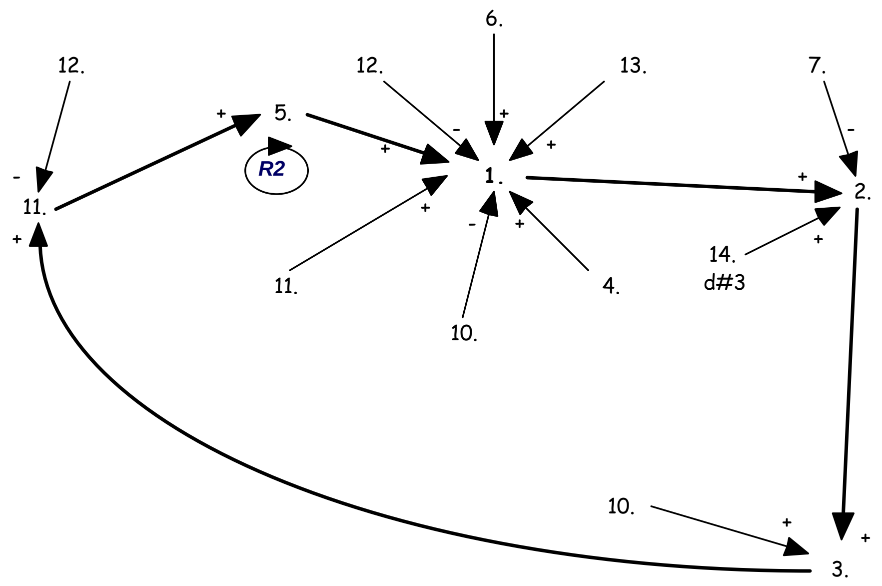


Figure 11-10 Longest Feedback Loop Identified

Subordinate loops are depicted at Figure 11-11, below.

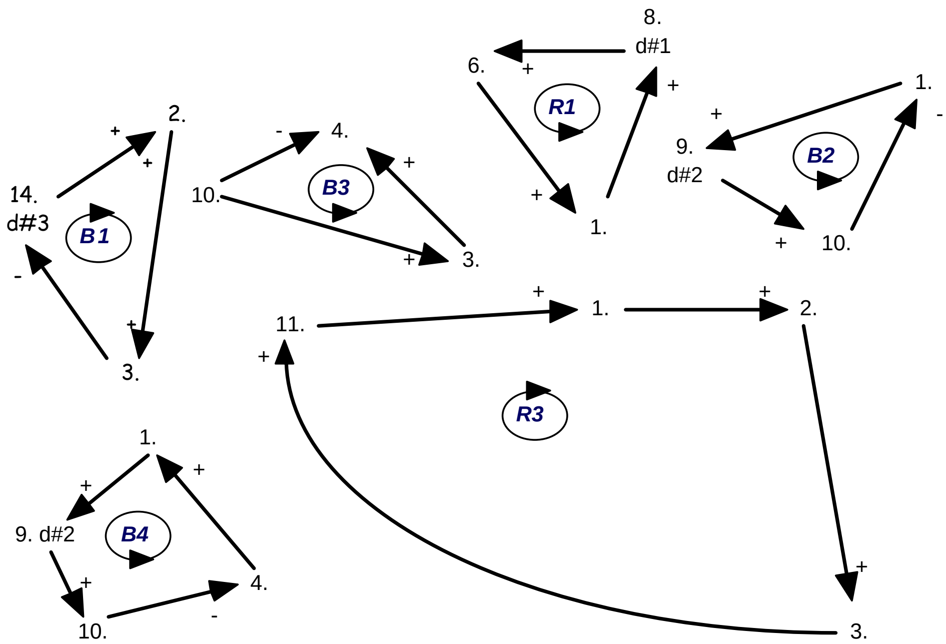


Figure 11-11 Ancillary Feedback Loops

11.24 Sequence of Calculations

The same sequence of calculations must be followed both for initialisation and simulation. Calculations are made in the specified sequence to ensure all influences are included and there is no double counting. When calculations for side loops are carried out, the value to be input to the main loop is held until the next iteration. This sequence is shown Table 11-2, where *node(iteration)* depicts the nodal value calculated during a particular iteration, and δ *(iteration)*n_1,n_2 depicts the influence (1) of 1 on 2. In the special case of initialisation, adjustments are made until the value calculated for node 1 at the end of the first iteration 1(1) is equal to the initial estimate, 1(0).

1(0) ⇒ 7(0) ⇒ 3(0) ⇒	+$\delta(0)_{1,2}$ – influence (0) of 1 on 2 +$\delta(0)_{7,2}$ – influence (0) of 7 on 2. +$\delta(0)_{3,2}$ – influence (0) of 3 on 2	⇒ 2(1)
2(1) ⇒	+$\delta(1)_{2,3}$ – influence (1) of 2 on 3 +$\delta(1)_{10,3}$ – influence (1) of 10 on 3	⇒ 3(1)
10(1) ⇒	+$\delta(1)_{10,4}$ – influence (1) of 10 on 4 +$\delta(1)_{3,4}$ – influence (1) of 3 on 4	⇒ 4(1)
3(1) ⇒ 12(0) ⇒	+$\delta(1)_{3,11}$ – influence (1) of 3 on 11 +$\delta(1)_{12,11}$ – influence (1) of 12 on 11	⇒ 11(1)
12(0) ⇒	+$\delta(0)_{12,5}$ – influence (0) of 12 on 5 +$\delta(0)_{11,5}$ – influence (0) of 11 on 5	⇒ 5(1)
12(0) ⇒	+$\delta(0)_{12,13}$ – influence (0) of 12 on 13	⇒ 13(1)
12(0) ⇒ 13(1) ⇒	+$\delta(0)_{12,6}$ – influence (0) of 12 on 6 +$\delta(1)_{13,6}$ – influence (1) of 13 on 6 +$\delta(1)_{1,6}$ – influence (1) of 1 on 6	⇒ 6(1)
12(0) ⇒ 11(1) ⇒ 6(1) ⇒ 10(1) ⇒ 4(1) ⇒	+$\delta(0)_{12,1}$ – influence (0) of 12 on 1 +$\delta(1)_{13,1}$ – influence (1) of 13 on 1 +$\delta(1)_{6,1}$ – influence (1) of 6 on 1 +$\delta(1)_{10,1}$ – influence (1) of 10 on 1 +$\delta(1)_{4,1}$ – influence (1) of 4 on 1	⇒ 1(1)

Table 11-2 Sequence of Calculations

As the main loop is navigated, only influences originating from 'upstream' nodes are included in the calculations. For example, when at node 3, upstream nodes having an influence are nodes 1, 2 and 7. Node 7 is not connected, except via node 2 and its influence has already been counted. However, node 1 is upstream from node 10, which influences node 3. So 1(0) is used to calculate 10(1) which, in turn, is used to calculate the influence (1) of node 10 on node 3. Influences originating downstream from the node where current calculations terminate must be held for the next iteration.

Initialisation calculations from Table 11-2, in the form of an Excel ™ spreadsheet are shown at Tables 11-3 and 11-4, below.

Input		Influences		Output		Comment
1(0)	0.5	(0) 1 on 2	0.4			Drug Availability at start of iteration. Input permitted.
7(0)	0.3	(0) 7 on 2	0.1			Input permitted
3(0)	0.7	(0) 3 on 2	0.1	2(1)	0.6	
1(0)	0.5	(0)1 on #2 on 10	0.4	10(1)	0.4	
2(1)	0.6	(1) 2 on 3	0.6			
	0.4	(1) 10 on 3	0.1	3(1)	0.7	
10(1)	0.4	(1) 10 on 4	0.2			
3(1)	0.7	(1) 3 on 4	0.3	4(1)	0.5	
3(1)	0.7	(1) 3 on 11	0.4			
12(0)	0.45	(0) 12 on 11	0.2	11(1)	0.6	Input permitted
12(0)	0.45	(0) 12 on 5	0.2			
		(0) 11 on 5	0.2	5(1)	0.4	
12(0)	0.45	(0) 12 on 13	0.3	13(1)	0.3	
12(0)	0.45	(0) 12 on 6	0.25			
13(1)	0.3	(1) 13 on 6	0.15			
		(1) 1 on 6	0.15	6(1)	0.55	
12(0)	0.45	(0) 12 on 1	0.05			
11(1)	0.6	(1) 13 on 1	0.1			
(6)1	0.55	(1) 6 on 1	0.15			
10(1)	0.4	(1) 10 on 1	0.1			
4(1)	0.5	(1) 4 on 1	0.1	1(1)	0.5	Drug Availability at end of iteration.

Table 11-3 Initialisation Calculations Summary

Link 1-2 (input 1. Drug Availability)	0.5	1	2	3	4	5	6	7	8	9
Lower Limit		0	0.24	0.34	0.42	0.46	0.52	0.58	0.62	0.7
Upper Limit		0.239	0.339	0.419	0.459	0.519	0.579	0.619	0.699	0.999
Value Returned		0.06	0.16	0.25	0.31	0.4	0.5	0.6	0.7	0.92
Link 1-2 Influence Calculated	0.4	0	0	0	0	0.4	0	0	0	0
Link 7-2 (input 7. User Ec Hardship)	0.3	1	2	3	4	5	6	7	8	9
Lower Limit		0	0.24	0.34	0.42	0.48	0.52	0.58	0.63	0.7
Upper Limit		0.239	0.339	0.419	0.479	0.519	0.579	0.629	0.699	0.999
Value Returned		0.05	0.1	0.14	0.18	0.22	0.27	0.31	0.38	0.6
Link 7-2 Influence Calculated	0.1	0	0.1	0	0	0	0	0	0	0
Links 3-14-2 (input 3. Cocaine Price)	0.7	1	2	3	4	5	6	7	8	9
Lower Limit		0	0.12	0.14	0.23	0.32	0.38	0.48	0.52	0.62
Upper Limit		0.119	0.139	0.229	0.319	0.379	0.479	0.519	0.619	0.999
Value Returned		0.7	0.54	0.42	0.34	0.26	0.2	0.16	0.12	0.1
Links 3-14-2 Influence Calculated	0.1	0	0	0	0	0	0	0	0	0.1
Link 2-3 (input 2. Drug Usage)	0.6	1	2	3	4	5	6	7	8	9
Lower Limit		0	0.24	0.34	0.42	0.46	0.52	0.58	0.62	0.7
Upper Limit		0.239	0.339	0.419	0.459	0.519	0.579	0.619	0.699	0.999
Value Returned		0.34	0.4	0.44	0.5	0.54	0.57	0.6	0.66	0.78
Link 2-3 Influence Calculated	0.6	0	0	0	0	0	0	0.6	0	0

Table 11-4 Initialisation Calculations - Selected Causal Relationships

11.25 The Initialised Illicit Drugs Diagram

The initialised illicit drugs diagram is at Figure 11-12, below.

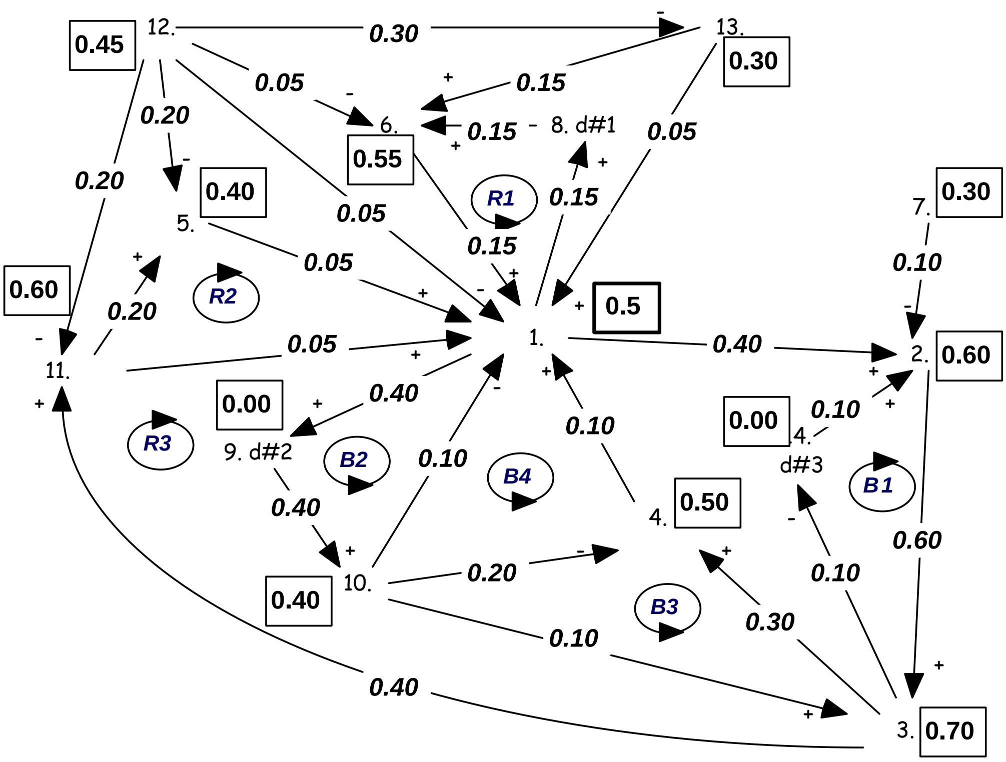


Figure 11-12 Initialised Illicit Drugs Causal Loop Diagram (1)(2)

Notes:

1. Initial estimates of nodal values, taken from Table 11-1, are shown in bold with rectangular borders.

2. Initial estimates of causal relationships are shown in bold italics.

11.26 Stepping Through the Simulation

The simulation to combat availability of drugs is run step-by-step. Once the diagram has been initialised, a scenario is developed to reflect desired remedial strategy, for example:

a. Increase international police intervention progressively, in a series of steps, from 0.45 to 0.60.

b. Making a one-off change to the shape of the relationship 1⇒10 which reflects increasing local police surveillance and intelligence gathering capabilities.

An example of the calculations is at Table 11-5, below, and graph of change of 1. drug availability as a result is at Figure 11-12.

Input		Influences		Output		Comment
1(0)	0.47	(0) 1 on 2	0.4			Drug Availability at start of iteration. Input permitted.
7(0)	0.3	(0) 7 on 2	0.1			Input permitted
3(0)	0.7	(0) 3 on 2	0.1	2(1)	0.6	
1(0)	0.47	(0)1 on #2 on 10	0.4	10(1)	0.4	
		(0)1 on #2 on 10	0.49	10(1)	0.49	
1=yes; 0=no	1	(0)1 on #2 on 10	0.49	10(1)	0.49	Increased surveillance capability. Input permitted
2(1)	0.6	(1) 2 on 3	0.6			
	0.49	(1) 10 on 3	0.13	3(1)	0.73	
10(1)	0.49	(1) 10 on 4	0.1			
3(1)	0.73	(1) 3 on 4	0.3	4(1)	0.4	
3(1)	0.73	(1) 3 on 11	0.57			
12(0)	0.6	(0) 12 on 11	0.16	11(1)	0.73	Input permitted
12(0)	0.6	(0) 12 on 5	0.18			
		(0) 11 on 5	0.44	5(1)	0.62	
12(0)	0.6	(0) 12 on 13	0.25	13(1)	0.25	
12(0)	0.6	(0) 12 on 6	0.21			
13(1)	0.25	(1) 13 on 6	0.15			
		(1) 1 on 6	0.1	6(1)	0.46	
12(0)	0.6	(0) 12 on 1	0.04			
11(1)	0.73	(1) 13 on 1	0.1			
(6)1	0.46	(1) 6 on 1	0.11			
10(1)	0.49	(1) 10 on 1	0.1			
4(1)	0.4	(1) 4 on 1	0.08	1(1)	0.43	Drug Availability at end of iteration.

Table 11-5 Simulation Calculations

At line 6 in Table 11-5, there is a user selectable input for the increased level of local police surveillance and intelligence gathering capability. This is selected at the start of the third iteration, or simulation step. See Figure 11-12.

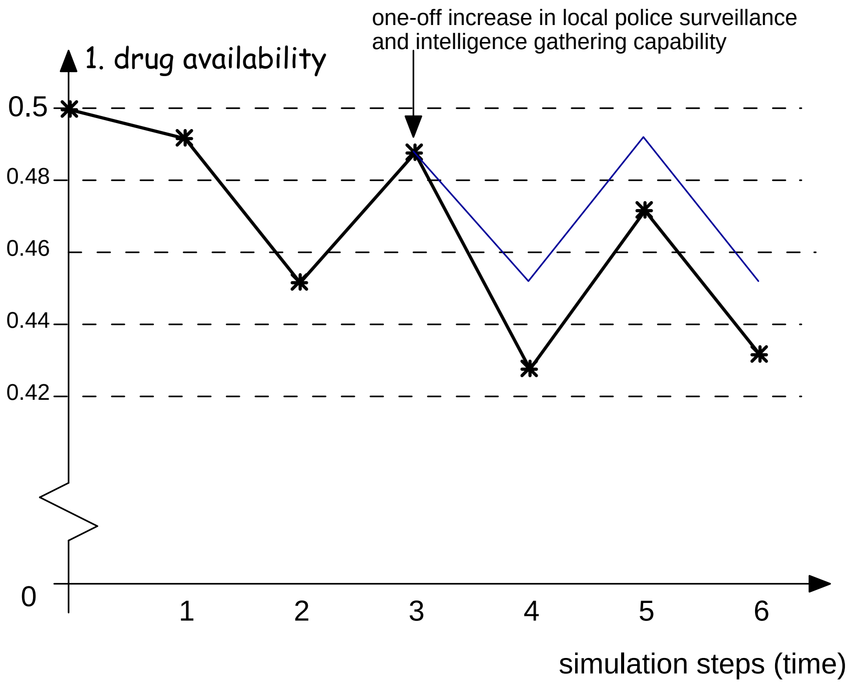


Figure 11-12 Simulated Impact of Strategies to Combat Illicit Drug Availability

11.27 Analysis of Simulation Results

International Police intervention produced an immediate reduction of drug availability from 0.5 to a level, which oscillated between 0.45 and 0.49. When local Police interdiction increased as a result of greater awareness of drugs on the street, achieved through increased surveillance and intelligence gathering capability, 1. drug availability dropped further. The light line in Figure 11-12 shows the level of 1. drug availability created by international police intervention alone. Combined impact of 12. international police intervention and 10. local police interdiction is shown at simulation steps 4, 5, and 6.

Sensitivity analysis revealed:

a. No contribution to the reduction of 1. drug availability for values of 7. user economic hardship less than 0.30.

b. Levels of 12. international police intervention, alone, above 0.60 had no effect.

c. Increasing 10. local police interdiction through increased surveillance and intelligence gathering capabilities, which changed the shape of the cause and effect curve as shown at Figure 11-13, had the effect of creating greater levels of police activity for given levels of 1. drug availability.

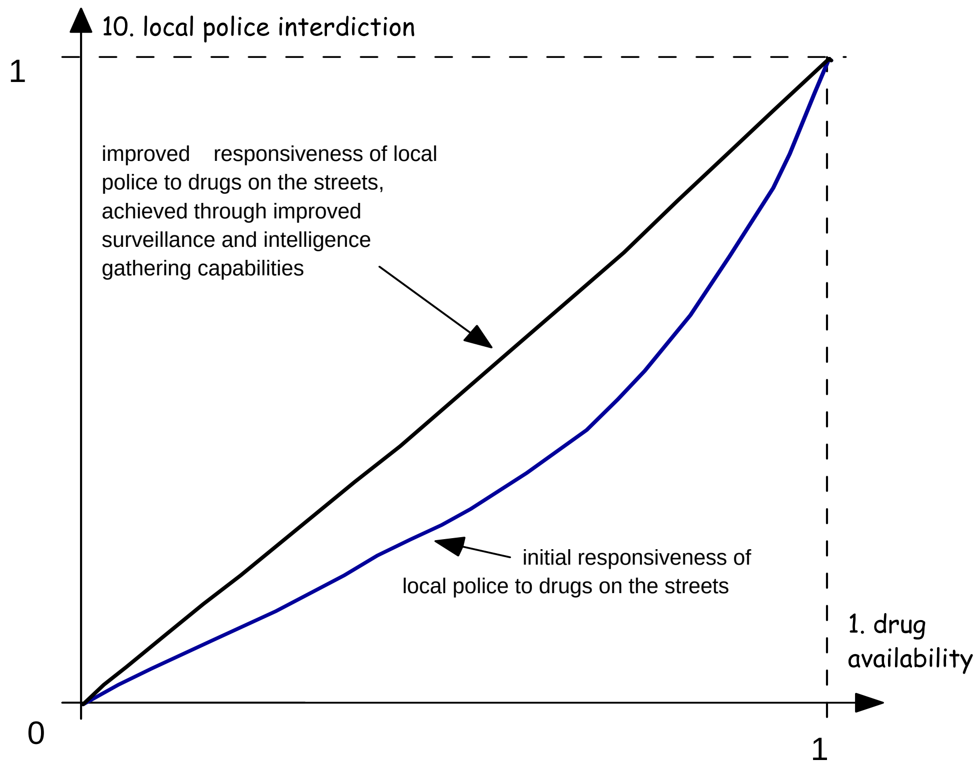


Figure 11-13 Improved Local Police Interdiction Capability

11.28 SD 'Front End' Tool in Brief - a Critique

The SD 'Front End' tool is designed to be used, in conjunction with IISD, to provide support to rapid analysis of wicked problems, when the opportunity presents to bring together a number of people with domain expertise for a limited period. This might be as short as a single half day and no more than a whole day. The main threat to achieving results described here is initialisation of the causal loop diagram. This is considerably more difficult than might appear at first. Success is critically dependent upon on the selection of initial nodal values. Achieving realistic, reliable and consistent initial estimates of nodal values is considered to involve low to moderate risk.

Further to discussion at 11.21, reliably estimating the causal relationships involves considerably greater risk for two reasons:

a. Potentially, there are myriad combinations and permutations of fuzzy patches to define the large number of causal relationships involved.

b. Considerable experience in formulating and analysing, cause and effect relationships is needed.

Poor choice in defining cause and effect relationships can mean that it becomes exceedingly difficult or impossible to initialise the diagram. Whilst this might be interpreted as a potential weakness in the design of the tool, in reality it reveals a major strength: the diagram cannot be initialised unless realistic estimates of cause and effect are made. This need for estimates of cause and effect compatible with estimates of nodal state values, forces repeated creation and testing of hypotheses about the cause and effect relationships. It also forces mental models regarding cause and effect to be surfaced and tested. In itself, this is a highly important outcome.

The SD ‘Front End’ tool is not a replacement for quantitative system dynamics modelling and it should not be used to simulate more than a few iterations. Practical limits to its usefulness as a simulation tool have not been established, as yet. A complete critique is contained in Chapter 12.

11.29 Overcoming Limitations of the Prototype Tool – Calculating Delayed Feedback

To create a delayed feedback loop where accumulation occurs, the influence value is simply held for the appropriate number of iterations. This involves the addition of a dummy loop which includes a node where state values are held temporarily. Graphical depictions of each of the relationships for each link are created as described in this chapter. Initial calculations are conducted as normal, but when simulations are conducted the influence value is held until required, a nominated number of iterations. The calculated output values are held in a temporary register until needed for the appropriate iteration.

11.30 Enhancement to SD ‘Front End’ Tool

Being able to identify the actual values of each cause and effect relationship ‘called’ during simulations would be useful aids in:

a. Selection of granularity, or fineness, of the approximation of causal relationships, noting that ‘hunting’ between values can occur in subsequent iterations, when coarse granularity results in adjacent fuzzy patch centroids being widely spaced, one being too high and the next being too low.

b. Providing insight which might inform the re-evaluation, as necessary, of cause and effect relationships.

11.31 Summary - Chapter 11

In this chapter a tool for analysing causal loop diagrams was demonstrated. It was shown that it is possible to analyse causal loop diagrams, producing remedial strategies for wicked problems as a result. The key limitation in the use of this tool lies with our own limited ability to reliably make meaningful estimates of non-linear cause and effect. Using this tool:

a. forces the enunciation of hypotheses regarding the nature of causal relationships,

b. does not artificially constrain causality to linear relationships,

c. supports the testing of hypotheses regarding causality, and

d. enables analysis of the veracity of an assumption (Coyle, 2000; Nuthman 1994) that causal influences at a node can be added.

Whilst further development is required, this tool helps bridge the gap between qualitative and quantitative analysis of dynamic, systemic, complex problems.

11.32 Significant Contributions Made in Chapter 11

Despite limitations of causal loop diagrams, their use as analytical and problem conceptualisation tools continues to grow. In this chapter a new tool and techniques for analysing causal loop diagrams are demonstrated. This is a significant contribution to the system dynamics body of knowledge. An unprecedented level of rigour has been added to the creation, analysis and interpretation of causal loop diagrams. This has the potential to change the way problem conceptualisation and first pass problem analysis, are conducted. It enables application of a level of rigour absent in such forms of influence diagramming, until now, with the exception of the form of influence diagramming espoused by Coyle (1996).

This demonstration showed that direct simulation of causal loop diagrams involving non-linear relationships is both possible and practical. Whilst simulation capability is limited, it is most useful in helping to identify where to apply resources and management effort. It has utility in the construction of remedial strategies for addressing wicked problems. These are significant aims of system dynamics analysis, regardless of that analysis being qualitative or quantitative. Efficacy of alternative strategies can be gauged using the tool and the techniques described in this chapter.

The value of using this tool and techniques lies in the removal of primary reliance on judgment and intuition in the analysis of causal loop diagrams. The result is capability to identify where to direct remedial strategies, the form of strategies that might be employed, and the first pass testing of those strategies through rudimentary simulation.

This tool also provides a vehicle for testing assumptions regarding the additive combining of causal influences at a node, an issues raised by Coyle (2000) and Nuthman (1994). This will be discussed further at Chapter 12.

CHAPTER 12: INTEGRATION OF QUALITATIVE AND QUANTITATIVE MODELLING TECHNIQUES: DISCUSSION

> …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).

Synopsis

This chapter reviews the need for the research described in this thesis. The key issues identified during the research are summarised. The principles of method derived are revisited in the context of the various case applications. Lessons derived from the case applications are also reviewed particularly to identify what was found to work, and what did not.

The qualitative *vs* quantitative debate was introduced at Chapter 1, noting that this thesis sought to find effective ways of integrating qualitative and quantitative forms of modelling, rather than investigating efficacy of each and making comparisons. The extent to which this research addresses specific qualitative *vs* quantitative research agenda issues raised by Coyle (2000), is reviewed using SWOT analysis. Details are at Annex F.

The value of the System Dynamics 'Front End' tool for first pass analysis of causality in dynamic feedback problems, described at Chapter 11, is discussed. Possible future developments are described. The need for further research is outlined.

This thesis focused on understanding the nature of ‘wicked’ problems with the aim of determining how best to address them. The effectiveness of human decision-making in environments where ‘wicked’ problems frequently occur, was examined. Principles of method for addressing ‘wicked’ problems were developed from a combination of empirical research, and a review of systems thinking and system dynamics literature. The need to enhance qualitative analysis, and the integration of qualitative and quantitative modelling were identified. The desirable outcomes of an integration of qualitative and quantitative modelling techniques were identified.

The efficacy of the principles of method was then investigated through action research. Lessons drawn informed the further development of the IISD framework and the integration of qualitative and quantitative modelling techniques. Barriers to effective decision-making were identified. Pitfalls in the conduct of system dynamics modelling were also identified. The System Dynamics ‘Front End’ Tool was designed to enhance qualitative causal analysis and to bridge the gap between qualitative and quantitative techniques. Why this work was essential, the work itself, the experience gained, and the need for further work are discussed in this chapter.

12.1 Why this Research Was Essential

Complex, dynamic problems confront us daily. They affect our lives in profound ways. They are immensely pervasive. Small and large corporations, Governments at all levels, and society generally, continually grapple with strategies intended to overcome ‘wicked’ problems, such as:

a. Correcting, or managing within, ‘boom and bust’ cycles.

b. How Government health, welfare, and law enforcement agencies might limit the supply and use of illicit drugs, so reducing consequential, detrimental effects on society.

c. How to dramatically reduce the incidence of HIV AIDS.

d. How to create health management strategies which minimise the impact of growing resistance of bacteria to antibiotics.

e. How to implement effective and lasting organisational change.

These and similar ‘wicked’ problems cost many millions of dollars. Some claim many lives. Lower order ‘wicked’ problems just make our lives difficult.

12.2 Human Decision-Making in Dynamically Complex Environments

Human ability to comprehend cause and effect mechanisms underlying these problems is limited, especially when cause and effect are not proximate in time or space, or sources of multiple influence do not lie within our immediate purview. Executive decision-makers and strategy developers do not necessarily have the most appropriate skill-sets for developing strategies to address 'wicked' problems, though they may face them every day.

12.3 Why Management of 'Wicked' Problems Can be Problematic

Human intellect is seriously challenged when it comes to figuring out how to fix 'wicked' problems. This situation is confounded when the extant state of a problem situation may have been created, in part, at least, by our previous attempts at corrective action. Availability of resources also frequently constrains how we might go about remediation. Identifying just where and how to expend limited resources can be critical.

12.4 The Research Challenge

This research was challenged to find highly effective ways of complementing human cognitive capability, and exploiting synergy between available tools and techniques. The ongoing qualitative *vs* quantitative argument is highly important to the system dynamics discipline, but it is something of a distraction from the main research aim. The challenge remains to develop decision-support techniques that are accessible, and as intuitive as possible. This thesis sought to aid recognition and understanding of complex problem situations leading to development of effective strategies to meet the types of 'wicked' problems described at 12.1. Observations from this research effort are:

a. *Problem Conceptualisation is Fundamentally Important*. In practice, many conceptual formulations start with the enunciation of ideas on a whiteboard or on a scrap of paper. These can become the basis for high-level strategies involving millions of dollars of investment. So, the basic argument becomes this "… if this is the way many powerful decision-makers do their thinking, why not make it as robust as possible, thereby reducing the risks of poor choice and poor decision-making?" Qualitative modelling can assist in determining where to best apply resources and effort. Quantitative analysis cannot always be completed in time or with sufficient confidence. The challenge then becomes to provide powerful, intuitive, and accessible qualitative techniques to:

(1) support analysis of system dynamics;

(2) support sensitivity analysis;

(3) facilitate identification of pressure points, to which management effort might be applied; and

(4) define the requirements for detailed quantitative analysis.

Coyle (1996) hits on a most important idea when he demonstrates that influence diagramming can lead logically to the formulation of a system dynamics model. Indeed, he states that the influence diagram and the system dynamics model are two forms of the same model. That was found nowhere else. That was recognised in this research as highly important and was exploited in the development of integrated qualitative and quantitative problem solving methods. This was demonstrated in the tutorial in Chapter 7. Support to conceptualisation is not provided by qualitative techniques alone. Sequences of divergent and convergent thinking are best supported by application of selected qualitative and quantitative techniques. Being able to move seamlessly between domains is considered important to enhancing understanding of complex dynamics. Some systems principles are best explained by qualitative techniques whilst dynamic phenomena are best demonstrated by quantitative modelling and simulation. This was demonstrated at Chapters 7 and 8.

b. *Group Model Building and Decision-Making.* With skilled support and facilitation, groups can work productively to build either qualitative or quantitative models. See Chapter 7. Groups need to feel comfortable working in either qualitative or quantitative domains. Being able to transition quickly, logically and seemlessly between these domains is considered essential. Working off-line to amalgamate cognitive maps to produce group maps is risky, though it might appear attractive to do so. Working in a group setting can support the critical analysis of individual or sub-group maps and can lead to creation of maps 'owned' by the group. Group decision-making and group model building are being used more frequently for good reason. At Chapter 10, it was shown that capturing data needed to populate models at high levels of aggregation, can be problematic. Employing groups of individuals with specific domain knowledge may be the only way to formulate models most appropriate to strategy development activities. Indeed, working in a group setting may be the only way to obtain reliable estimates of variables for input into those highly aggregated models.

c. *Decision-Making Cannot be Separated from Values and Beliefs*. How decision-makers think is inextricably linked to the way they feel about a problem situation. At Chapter 2, it was shown that mental models are linked to values, beliefs, feelings, and individual and organisational behaviour. Mental models relevant to the focal problem situation must be elicited and examined as far as practical in the time available. This will involve a variety of skills, and application of a mix of qualitative and quantitative modelling techniques. But, relying on only one form of modelling is unlikely to be enough. As suggested above, being able to transition quickly, logically and seamlessly between qualitative and quantitative modelling is considered essential.

d. *Reliance on Naturalistic Decision-Making Even in Deliberate Decision-Making Settings*. At Chapter 2 it was argued that 'gut-feeling', and other forms of naturalistic decision-making are used more frequently than previously acknowledged, even in deliberate decision settings. How and why this occurs needs to be understood because it affects how we might provide support to decision-makers. The types of decision-making actually employed impacts on model development and the acceptability, to the sponsors, of models produced. There may be insufficient time for full rounds of data gathering and quantitative analysis, or data may be inaccessible as was found in Chapter 10. Under these circumstances, decision-makers may choose to ignore systematic decision support, reverting instead to naturalistic decision-making. This brings attendant risks. To reduce such risks, at least quick but comprehensive qualitative analysis might be used, noting that such analysis may demand high levels of background knowledge and experience in quantitative modelling, as identified at Chapter 11.

e. *Misperceptions of Systemic Feedback*. Success in demonstrating how systemic feedback manifests itself demands high levels of expertise in both qualitative and quantitative modelling. Quantitative modelling and simulation are most useful for demonstrating dynamic phenomena.

f. *Identifying Pressure Points - Where Best to Apply Management Effort*. Being able to identify where to apply effort and limited resources is a highly important management skill. Qualitative modelling can be effective for identifying where to apply effort and resources. At Chapters 7 and 10, the use of influence diagramming, for this purpose, was demonstrated. Though not measured, it appears that qualitative analysis is under-exploited relative to its comparative utility.

One possible explanation is that our ability to mentally simulate all but the simplest problems, is limited. Sweeney and Sterman (2000) convincingly demonstrate human inability to master simple ‘bathtub dynamics’, that is simple graphical integration. Even experienced system dynamics practitioners fail here, as was demonstrated by Sterman with a live audience of around 250 system dynamics practitioners at the 2000 International System Dynamics Conference in Bergen, Norway. Limited, or poorly-practiced (it is suggested), mental simulation skills may explain our reliance on incremental development of quantitative models. Incremental development eases demands on our mental simulation faculties. Whilst there is no evidence to the effect, it seems this is an unfortunate product of our lack of mental exercise.

A further reason offered for lack of reliance on qualitative modelling for strategy development is that the primary tool we might use, causal loop diagramming provides insufficient functionality for this purpose. Whilst the SD ‘Front End’ tool was designed as an outcome of this research, to overcome some of the limitations of causal loop diagramming, its use is not intuitive for the novice. This has little to do with the design of the tool. Rather, it is because causal loop diagrams can be misleading even for experienced modellers, as Sterman notes… ‘even those who advocate the use of qualitative system dynamics methods are careful to point out that in all successful applications of such qualitative methods the analysts have had extensive experience in formal model building (Richardson, 1985: 158).’

The form of influence diagramming proffered by Coyle (1996), as demonstrated at Chapter 7, is preferred over causal loop diagramming because:

(1) it has logical rules, open to far less interpretation; and

(2) is based on system dynamics common modules, having a direct equivalence to stock and flow diagrams.

In some cases, development of strategies for quick implementation may be an important driver. Many years of observation of Defence and Government decision-making leads the author to suggest qualitative analysis lies behind many high-level decisions made in short time. Often the use of quantitative analysis is avoided because it is not clear which techniques might be best applied. Also, the necessary data may not be available in the timeframe.

A government dealing with a taxation issue may not be able to wait for economic modelling to be completed before developing a strategy or policy. Arguments delivered in the House are unlikely to be presented in the form of a quantitative model. However, qualitative models frequently form the basis of a politician's oration through which appropriate concepts and linkages are argued.

Arguments built on qualitative analysis can have high utility. Eden, Ackermann and Williams (1997) demonstrated this. Arguments are made more convincing when supported by quantitative analysis, providing that that analysis can be demonstrated as sound. Quantification may not be a pre-requisite to strategy development. Again, being able to transition quickly, logically and seamlessly in an iterative way from qualitative to quantitative modelling, is seen as essential.

g. *Importance of Communications in Decision Cycles*. Developing unambiguous communications supported by appropriate qualitative or quantitative modelling will aid understanding. Quantitative techniques are least open to interpretation, and for those who are fluent in mathematical methods, there is least opportunity for ambiguity. But, whilst the mathematics is universal, it is not universally understood by decision-makers. It was explained at Chapter 2 that the use of symbols and icons, that is semiotics, in qualitative modelling brings richness in communication. However, a shared understanding of the meaning of the symbology, is essential. Despite their known weaknesses, causal loop diagrams are widely used to communicate systems ideas. Unfortunately, causal loop diagrams can mislead even experienced modellers. It was argued at Chapter 7 that influence diagrams built according to Coyle's (1996) rules are less likely to be misinterpreted than causal loop diagrams. Like mathematics, influence diagramming requires a high level of pre-requisite knowledge. In the case of influence diagramming an understanding of stock-and-flow systems 'modules' and the significance of those 'modules', is needed.

h. *Demands Created by Complexity*. Capturing, depicting, analysing, communicating about, and summarising complex situations require considerable skill. Particular skill is required to depict highly complex ideas in the simple, intuitive ways often demanded by senior executives. This means working at high levels of aggregation where qualitative modelling is most appropriate.

i. *Analysis of Alternative Possible Futures*. Modelling, either qualitative or quantitative, enables the analysis of strategies and possible futures. See Forrester's (1987) comment at the beginning of this chapter. Modelling is not intended to be predictive, rather it is intended to support the development of understanding and mental agility. Understanding and mental agility are essential enablers to adapting to changing circumstances. IISD, as explained at Chapter 6 and demonstrated at Chapter 7 is offered as a methodology for supporting the development of strategies that will survive changing circumstances

j. *Superior Insights Produce Superior Learning*. System dynamics analysis can be most valuable in revealing insights into complex problems and helping in development of 'double loop' learning. The case studies revealed situations where learning failed. It is suggested that failure to learn is frequent, and is frequently overlooked. Learning is central to any modelling effort, qualitative or quantitative. Models must be kept simple, simple enough to enable full understanding and to facilitate complete debugging, but they need to be sophisticated enough to represent the real world in a meaningful way. Opportunities to identify how and where insights are created may be enhanced by selective, integrated use of qualitative and quantitative system dynamics techniques.

k. *Finding Out About a Problem Situation*. Regardless of methods used to find out about a problem situation, communicating systemic ideas, taking an holistic view, accommodating perspectives and appreciating the behaviour of complex systems and systems-of-systems, are essential elements. It is also important that some form of graphical depiction of the complexity of human affairs is produced. This is necessary but may not be sufficient for defining some problems. Often this needs to be supported by specific, quantitative functional descriptions.

l. *Call for Quantification of Causality*. In Chapter 3, Chief of Army made a clear call for quantification of causality. Richardson (1985) showed limitations of causal loop diagrams, amongst which was a lack of quantification of causality. More recently and in response to recognition of this need, Kwahk and Kim (1999), Kim (2000) and others have attempted to quantify causality in cognitive maps. Coyle responded to the need, long recognised by him, by developing system dynamics influence diagramming, a form having direct equivalents in computer-coded system dynamics models. Coyle's is the only methodology found to have direct linkage to quantitative system dynamics modelling. Causal loop diagrams have been used in hybrid stock-and-flow models for more than 25 years. In hybrid stock-and-flow models, causal loops do not quantify causality. Rather, they guide the formulation of the algebra of auxiliary functions needed to control the rates in the stock-and-flow model.

   Recognition of the call for quantification of causality led to the creation of the System Dynamics 'Front End' Tool described at Chapter 11.

m. *Application of Principles of Method*. The need for integration of qualitative and quantitative methods to address 'wicked' problems led to formulation of a set of principles of method at Chapter 6. These principles are encapsulated in IISD with the specific aim of application to the remediation of 'wicked' problems, through the integrated use of qualitative and quantitative methods. A central theme in IISD is that superior insights gained through the use of both qualitative and quantitative system dynamics techniques leads to superior 'double loop' learning about 'wicked' problems. How the various techniques fit was described at Figure 6-4. Successes and failures of IISD were described in the case applications, Chapters 8-10. Exhaustive analysis of IISD was not possible, and the need for continued development is acknowledged, particularly in the light of the addition of the System Dynamics 'Front End' Tool to the IISD toolbox.

12.5 General Lessons from This Research

General lessons drawn from this research are:

a. Full and continued support of an executive champion is needed to ensure access to stakeholders and to mitigate gatekeeper controls. This is particularly important in facilitating access to the data needed for quantitative modelling. Qualitative presentation of problem conceptualisation and problem definition issues can be critical to securing the support of the champion at the outset, then keeping that person informed.

b. Data sets to populate highly aggregated models may need to be specially collected. Data collection takes time and may involve considerably more than extracting data sets from extant repositories such as databases. The more highly aggregated the model, the more likely it is that estimating through employment of nominal group technique, or similar, may be needed (witness Forrester's Club of Rome model). When this data is unavailable or not easily extracted from extant sources, failure in modelling projects can result.

c. The conceptualisation phase of a modelling project is critically important. 'Quality thinking' early, is essential to success. The more effective and readily accessible the techniques for finding out about a problem situation are, the greater the opportunities for success.

d. Stakeholder involvement is a key principle, and qualitative techniques have greater utility than quantitative analysis in fostering stakeholder involvement.

e. Tools such as cognitive and concept mapping have been demonstrated to be very effective for recording ideas, representing facets of knowledge, and depicting the strongly-coupled nature of 'wicked' problems, and for fostering dialogue.

f. No single elicitation or conceptualisation technique is sufficient, by itself. Selection of particular techniques to be used in given situations should be informed by stakeholders' skills in communicating about systemic events, preferences for information presentation, and their choice styles.

g. The notion that building a better understanding through modelling is more important than the model itself, is as relevant now as when Forrester made this same observation some 30 years ago.

h. An axiom of the system dynamics discipline is that the focus must remain on problem solving rather than creating 'the model'. We model the problem, not the system. A key criterion for 'success' then, is the degree to which the modelling process, qualitative or quantitative, assists in the decision-making. Achievements in helping stakeholders understand and challenge their mental models is seen as highly important. See Forrester's (1987) comment.

i. There are many pressures on modellers. Despite the pressures, modellers must not allow themselves to be distracted from proper procedures, based on the application of structured, quality assured, methodology.

j. Launching directly into quantitative modelling not adequately supported by problem conceptualisation, is problematic. An integrated approach, as described at Chapter 7, augmented as appropriate by use of tools such as the System Dynamics 'Front End' Tool for first pass and sensitivity analysis, is considered essential.

Objectives of qualitative and quantitative modelling are fundamentally the same. However, quantitative modelling offers greater potential, as Forrester (1987) observes, to "…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... ", but to do so involves considerably more effort than when qualitative techniques are used.

When to use qualitative and when to use quantitative modelling has been the focus of long-running arguments. The research activities described in this thesis were well advanced before Coyle (2000) suggested the qualitative *vs* quantitative research agenda described at Annex F, results of which are discussed below.

12.6 Coyle's (2000) Research Agenda - SWOT Results in Brief

Issues raised by Coyle (2000) are shown in italics, and the extent to which this research effort addressed the issues, follows:

a. <u>*Issue 1*</u>*: How much value does quantified modelling add to the qualitative analysis?… Qualitative modelling may be imperfect but is quantification always better?* Pressure points identified in rigorously constructed influence diagrams become the foci for the application of management effort. The System Dynamics 'Front End' Tool applied to causal loop diagrams supports testing of logical structure, enables the identification of pressure points and testing of the sensitivity to different strategies. The utility of causal loop diagrams has now been increased to the point where useful strategies can be derived, in many cases, without the need to build conventional quantitative system dynamics models. The gap between qualitative and quantitative modelling has been significantly reduced as a result.

b. *Issue 2: Identifying exactly where insights occur.* IISD has been built on the proposition that superior understanding leads to superior learning, noting that understanding is produced when insights occur. In Chapter 2, how decision-makers think was considered with the aim of identifying how insights develop, and, in turn, how that informs decision-making processes. A variety of ways of addressing a problem and fostering the creation of insights can only be employed if the analyst has a selection of effective qualitative and quantitative techniques to draw upon. The reaction of the stakeholders, as insights develop, can be gauged. In turn, this can inform choice of which techniques might be used to further improve the creation and exploitation of insights.

c. *Issue 3: Identifying more precisely the types of models and the domains of investigation in which difficult models are likely to arise.* This issue was not specifically addressed.

d. *Issue 4: Consideration of how [‘soft’] variables might acceptably be measured.* The differences between parameters, variables and notional concepts of variables, that is ‘soft’ variables are not clearly enunciated in the literature. Dimensionless models, by definition cannot be quantified. Treating the relationships between soft variables in the same way as risk factors, depicting them graphically on a scale of 0 to 1, was demonstrated at Chapter 11. Further investigation is needed.

e. *Issue 5: Attempting to establish principles for deducing the shape and values of non-linearities.* Considerable skill is needed to outline the shape of non-linearities and estimate values. Skill builds with experience as a system dynamics modeller. There are many opportunities to get the shape of non-linearities wrong. This was found during early attempts to initialise causal loop diagrams. See Chapter 11. The System Dynamics ‘Front End’ Tool demonstrated at Chapter 11 provides utility to estimate the shape of non-linearities, then test those estimates using trial and error.

f. Issue 6: *Developing a technique for handling non-linear effects on a given variable, so as to avoid double counting.* This was demonstrated at Chapter 11.

g. Issue 7: *Defining a procedure for establishing the forms of relationship involving multipliers, that is, whether factors are multiplicative, additive, minimising or whatever.* The System Dynamics 'Front End' Tool is built on an assumption, as is the work of Kwahk and Kim (1999) and Kim (2000), that influences at a node are additive. Coyle (2000) and Nuthmann (1994) argue this assumption needs formal investigation.

It is suggested that the System Dynamics 'Front End' Tool now provides a vehicle for testing the veracity of the assumption that influences at a node in a causal loop diagram (influence diagram or cognitive map) are additive. Planned developments of the System Dynamics 'Front End' Tool will cater for a range of strategies for combining the influences at a node, but each will involve some form of addition. The issue described here by Coyle is one deserving greater attention than could have been addressed late in this research effort, and has broader implications for the system dynamics community.

h. Issue 8: *Some… difficult problems… involve parties that have conflicting objectives, are in discord or are even in violent conflict.* This research identified complicating effects of stakeholders with conflicting objectives, existence of systems of knowledge-power and barriers to addressing 'wicked' (difficult) problems. Employing IISD, as described at Chapter 7, helps manage situations where conflicting objectives, or discord, exist. The ramifications of violent conflict were not addressed.

i. Issue 9: *Finding some formal measure of the extent to which uncertainties in formulating equations or obtaining data affect the reliability of the model (measuring variations from a reference mode by sensitivity testing guided by statistical design?).* This was not specifically addressed. It is an issue for the broader system dynamics community to consider. However, one use of the System Dynamics 'Front End' Tool is to assist in identification of data sets to be gathered before quantitative models are built. It also offers the opportunity for comparison of results achieved through alternate approaches to problem analysis.

12.7 Need for Future Work

This research was not designed specifically to answer the questions raised by Coyle (2000). Whilst a number of those questions were addressed in the normal course of this work, many remain unresolved. Further work is required.

Detailed investigation of the veracity of additive combination of influences at a node using the System Dynamics 'Front End' Tool is needed. Expansion of the functionality of the System Dynamics 'Front End' Tool is required to enable investigation of alternate ways of combining influences. This work is planned.

Further to issues raised by Nuthmann (1994) and found in Chapters 10 and 11, further investigation of human judgement in estimation of values of parameters for input to system dynamics models designed at high levels of aggregation, is required.

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ANNEX A: CONCEPT MAPPING TUTORIAL

A.1 Concept Mapping

The concept mapping methodology used throughout this work follows cognitive mapping techniques of Eden (1988; 1994). Cognitive mapping derives from the Psychology of Personal Constructs developed by pioneering cognitive psychologist, George Kelly (1955). In Eden's terminology, a cognitive map is a personal or individual's mind map, whilst a concept map is a consolidation of the views of several individuals. The term 'cognitive map' recognises that cognition belongs to the individual and not to a group or organisation.

A.2 Personal Constructs Involving Fuzzy Logic

Unlike digital computers that are programmed to operate using classical logic, human thought and, hence, our personal constructs (Kelly, 1955) are built around 'fuzzy logic'. Pinker (1997) explains fuzzy logic as follows:

> In many domains people do not have all-or-none convictions about whether something is true [or false] (Pinker, 1997: 101).

Life and how we view it is not black and white. We do not all agree, even when we see the same thing. Kosko (1994) points out that one person sees a glass of water as half full, another sees it as half empty. He goes on to ask, whether after a further sip is taken, is this same glass still half full? To accommodate this we need to think in terms of fuzzy logic. Cognitive and concept maps throughout this dissertation are constructed in a way that exploits this type of logic, the logic of debate, dialogue and discourse about real world problems. Kosko (1994) and Taber (1991) refer to these maps as fuzzy concept maps.

A.3 Fuzzy Logic Links Between Concepts

To get started in building and analysing concept maps, we only need three types of fuzzy logic links:

a. Causal. Causal relationships are represented by arrows, where each arrow means 'leads to… ', such as is expressed in the statement 'smoking *leads to* heart disease. This does not mean all smokers will suffer from heart disease but suggests there is strong evidence to this effect, noting all people who smoke will be affected, at least to some extent. In our statement, there are two concepts where the first is expressed as a call to action in positive terms, in turn, affecting the latter concept in a positive way. These concepts may be more fully expressed as:

(1) partaking in the practice of smoking cigarettes, and

(2) the onset of heart disease later in life.

b. Connotative. Connotative relationships are typically depicted by lines without arrowheads. To start, we will use dotted lines to depict connotation. Here causality may act in either direction at different times or under varying circumstances. This type of link suggests causality is ill-defined, open to interpretation, or requiring further observation and investigation. Connotative links are often use to connect concepts having a system policy input. Varying such a concept may have significant impact on connected concepts. Alternatively, the nature of the relationship may be dependent upon initial conditions.

c. Conflict. Conflicting relationships are a special case of the connotative, but where the concepts at the ends of each line cannot co-exist without conflict, or a state of stress being created. Several different conventions are used to denote conflict. For example, either a red line is used or the link is marked 'CONFLICT'.

A.4 Building Concept Maps – A Short Tutorial

In a class exercise, a group of postgraduate students were tasked to produce a concept map of a problem that they had recently discussed, or was topical. In this exercise, they were to use each of the three types of link defined immediately above. The start point was a bland statement:

Smoking *leads to* heart disease.

Students were quick to point out that it was more appropriate to use the words *leads to* rather than to make the statement which appears on packs of cigarettes in Australia:

Smoking *causes* heart disease.

A statement using the verb *causes* suggests smoking always produces heart disease. Such immutable causality is only found in the physical world. Consider the following example from Newtonian Physics:

> Increasing the force applied to a moving body will c*ause* its acceleration to increase proportionally to the increase in force.
>
> (Newton's Second Law: $\sum$ *Force = mass x* $\sum$ *accelerations).*

Logic from our physical world example does not fit well with what we know about the relationship between smoking and heart disease. It is not clearly established that a smoker who increases the number of cigarettes smoked per day from, say, ten to twenty will double the likelihood of developing heart disease. A person may develop heart disease by continuing to smoke as few as five cigarettes per day, or despite quitting smoking totally.

Further, a differentiation may be made between active and passive smoking. This may be depicted using the terminology *rather than*, signified by the use of an ellipsis (…), as used by Eden (1988). Some non-smokers in Australia, for example, have argued successfully and won in litigation against employers who have not provided a smoke-free workplace. Their legal arguments were built around the following:

> Passive smoking … (rather than) active smoking alone *leads to* heart disease.

Alternative way of depicting this *rather than* (…) relationship is shown at Figure 1-2:

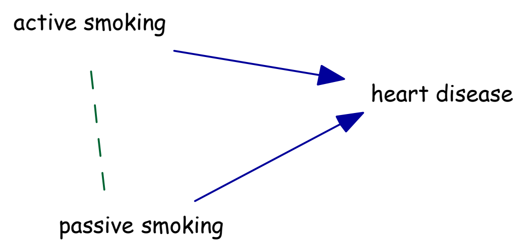


Figure A-1. Active Rather than Passive Smoking Leads to Heart Disease (1)(2)(3)

<u>Notes:</u>

1. Each of the concepts has been shortened for convenience. However, a note of caution is needed. Each mapped concept is normally and deliberately coded with an active verb so that each of the ideas, notions, personal constructs or concepts contained in them constitutes a *call for action*. This is both an aid to minimising ambiguity and to guide the process of 'manage and control' which is meant to flow through pairs of linked concepts. A *call for action* at the tail (source) of a causal link is intended to result in some form of management or control action at the head (sink) of that link.

For a more detailed explanation of *call for action*, see Eden and Ackermann (1998a: 94, 160, and 290).

More fully expressed, concepts in this figure are:

- partaking in the practice of active smoking of cigarettes,
- being exposed to passive smoking of cigarette smoke, and
- the onset of heart disease later in life.

2. Concepts are normally numbered, simply for identification. As this map will be quite small, numbering is omitted.
3. For an explanation of contrasting or opposite poles, see Eden and Ackermann (1998a: 94 and 290).

The solid (blue) arrows depict fuzzy *leads to* causality. The dotted (green) line depicts a connotative relationship between active smoking and passive smoking. It is quite feasible that passive smoking by a bartender who worked for years in a smoke-filled bar might have the same effect on the individual’s health as a comparable period of active smoking.

Characteristically, connotative relationships are difficult to describe succinctly. They are difficult to quantify, often involving an element of chance. This can be problematic for those who seek to launch more fully into quantitative analysis.

Underling this thesis is the observation that quantitative descriptions are applicable only to certain classes of problems, whereas all problems may be described in qualitative terms. Further, problems are much more likely to be described in qualitative terms before being analysed in detail and described in quantitative terms, or as an enabler to quantitative analysis. Concept mapping is only one way of revealing the underlying nature of problems. Alternate methods that might have been used are described at 6.23, 6.25, and 7.6. The choice of concept mapping was heavily influenced by considerations of cognition and decision-making, at Chapter 2.

In our tutorial example, students argued that there could be myriad factors affecting the onset of heart disease, including:

a. stress;

b. a genetic predisposition to the disease;

c. lack of exercise;

d. exposure to environmental pollution;

e. having elevated blood pressure, noting individuals may have a predisposition to hypertension, whilst others may also suffer from hypertension aggravated by a lack of exercise or stress; or

f. lifestyle factors such as levels and types of fatty food intake are likely to contribute to heart disease via an intermediate mechanism, increased cholesterol.

A.5 Products of Mapping

Whilst the group of students could not possibly uncover the whole story of heart disease in a single workshop session, it became obvious to them that the focal problem was a multi-factorial one with many concepts and complex interrelationships. The final form of the concept map produced after about 30 minutes of discussion by a group, who had not seen concept mapping before, is shown below at Figure 1-3. It is important at this point to note that the students felt:

a. such maps are a powerful form of relational shorthand, but

b. the final form of the map could <u>not</u> be unanimously agreed because they had neither the data not the medical expertise to validate the model so depicted, and

c. a strong sense of ownership because they had developed the model (they did not accept so readily models built by other groups – invariably they treated them with caution).

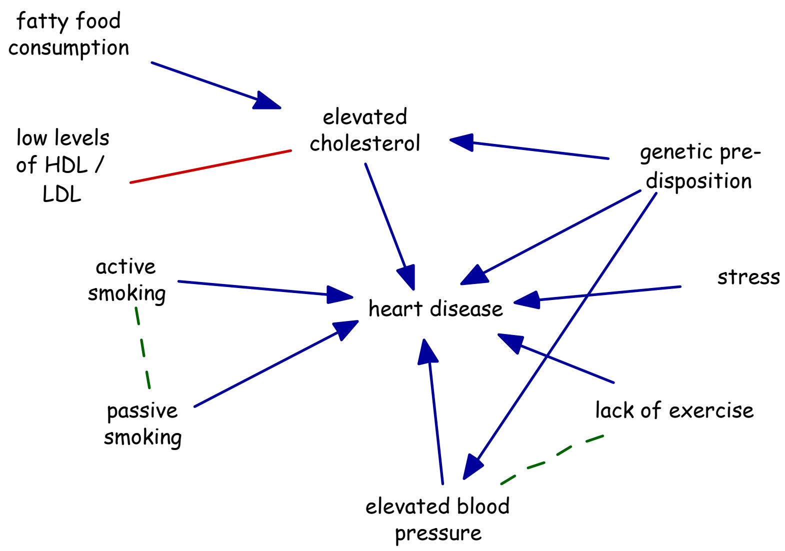


Figure A-2. Partial Map - Smoking and Other Contributors to Heart Disease

A short period of contemplation should lead the reader to the following conclusions:

a. Even with a relatively small number of concepts, as shown in this map, the interrelationships exhibit strong coupling.

b. Several other concepts might have been included. For example, age of persons involved, or period of exposure to pathogenic environments, were not identified or included in this initial map.

c. There are several links we might question. At this stage there is nothing to suggest that increasing the amount or frequency of exercise might reduce blood pressure and, hence, the risk of having a heart attack. Heart attack is a greater concern than the existence of heart disease, *per se*.

d. Further to the point made earlier about a strong sense of ownership, acceptance of the map is much more likely if the reader is involved in its development. A map developed without close involvement by stakeholders may not be accepted by them.

Cognitive psychologists Bannister and Mair (1968) analysed Kelly's foundation work and subsequent developments in this area of psychology. They provide a comprehensive and critical review of the theory and applications. Their work strongly suggests Kelly's views expounded 13 years earlier remain valid and most useful in the interpretation of exploratory propensities of the individual mind. They forecast that

Kelly's theory and methodology would come to hold a special place in any science of behaviour since he is concerned explicitly to conceptualise the theories, methodologies and behaviour of men in their scientist-like qualities and endeavours. Cognitive mapping, knowledge elicitation, recording, and analysis based on Kelly's theory is considered sound.

A.6 Experimental Foundation

Klein and Cooper (1982) in a collaborative research task with the British Ministry of Defence, observed that human decision processes always take place within the subjective world of the individual decision-maker. Even when presented with the same information, decision-makers view the same problem quite differently, potentially producing different answers. To investigate decision-making behaviour, they set up a wargame in which each player was given the role of the same senior decision-maker. They mapped how players responded to a sequence of pre-planned events in the game. They used cognitive mapping to compare how different players behaved in exactly the same sequence of objective circumstances. In respect of cognitive mapping, Klein and Cooper (1982) found:

a. A cognitive map may be viewed, as an external model of a decision process, a model that can represent the complex ideas and interrelationships perceived by a decision-maker in a concise, tangible and manageable form.

b. In this framework, a cognitive map is a means of communication, not only for the transfer of perceptions and ideas between different decision-makers, but also for aiding an individual decision-maker to elucidate his own perceptions [a tool for facilitating metacognition].

c. Cognitive maps may be used:

   (1) as a form of communication in the process of *problem negotiation* between the client and analyst as described by Eden, Jones, and Sims (1979);

   (2) in *teaching* decision-making skills;

   (3) for *assessing* the ways in which decision-makers acquire problem-solving strategies as they learn about a new problem and its environment; and

(4) in *decision-making* research.

In respect of perspectives of decision-makers, Klein and Cooper found:

a. One decision-maker can see the same objective situation in a completely different way from another.

b. Decision-makers approached a given scenario according to the [initial] confidence they had in their own ability.

c. In their second encounter with the game, players appeared to take it more seriously. Players may have realised that the game was very similar to Command Post exercises with which they were familiar, and that the game was non-trivial.

d. Players’ responses were dynamic: perceptions changed. Some aspects of the cognitive maps recorded during subsequent games involving a given individual, were found to be elaborated in finer detail, whilst others were lost from consideration.

ANNEX B: *ThreeTwoOne* Pty Ltd Model

Title: Concrete Batching Plant - Array Version dated 1 Nov 98
Filename: A:\CRETRRRY.SIM
Author: ALAN McLUCAS

Description

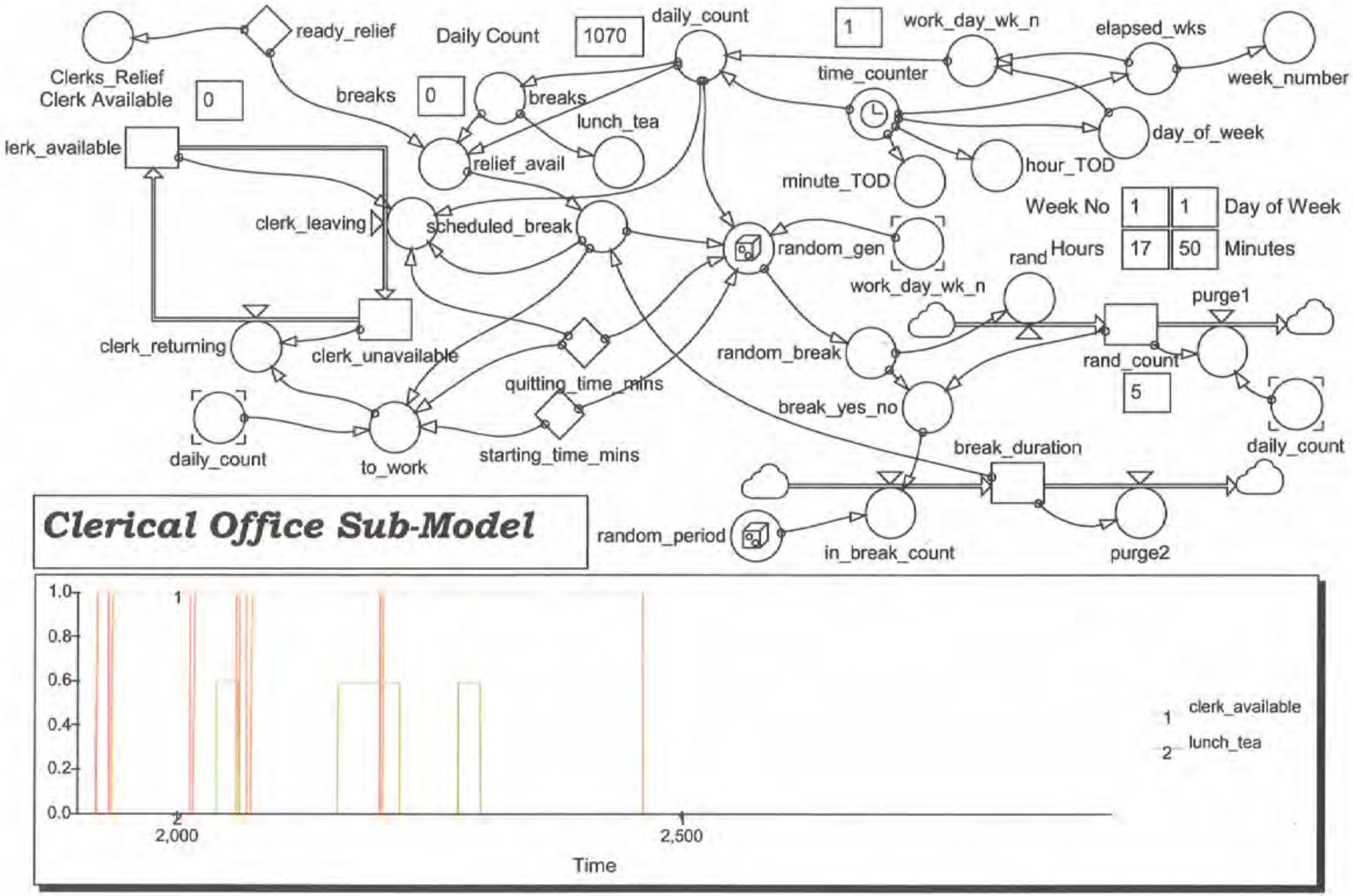
This model simulates the operation of a concrete batching plant, ordering, and delivering.
This model takes the "Delivery Trucks Sub-Model" from CRETE5AR and expands it into an array sub-model to acccommodate up to eight trucks.

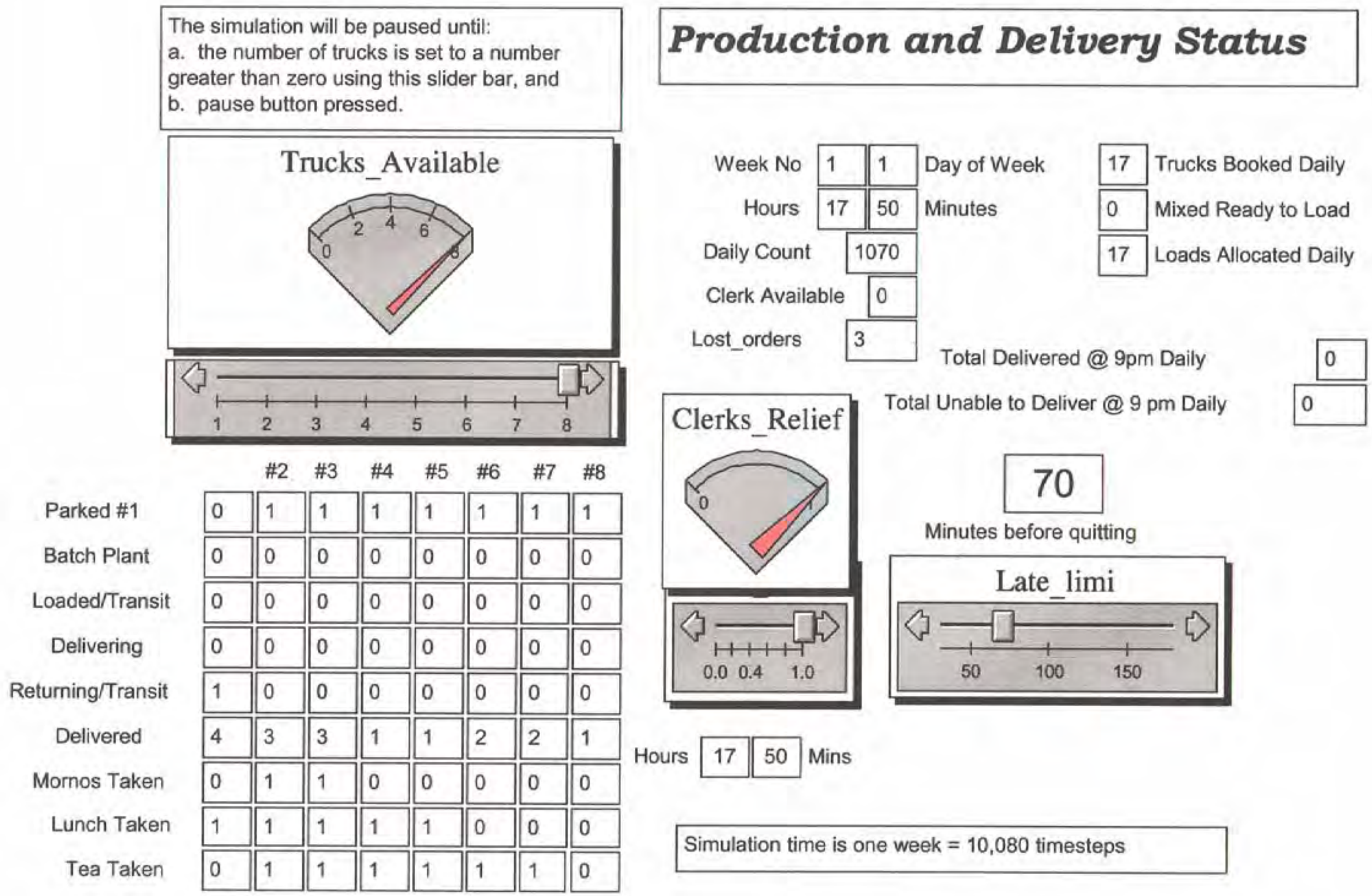
The number of trucks is user-selectable. This facilitates testing sensitivity to changing numbers of trucks. Employment of a relief to fill-in for the clerk during scheduled breaks is also user-selectable. However, no provision has been made in this model for a relief to be employed during unscheduled 3-5 minute breaks taken by the clerk.

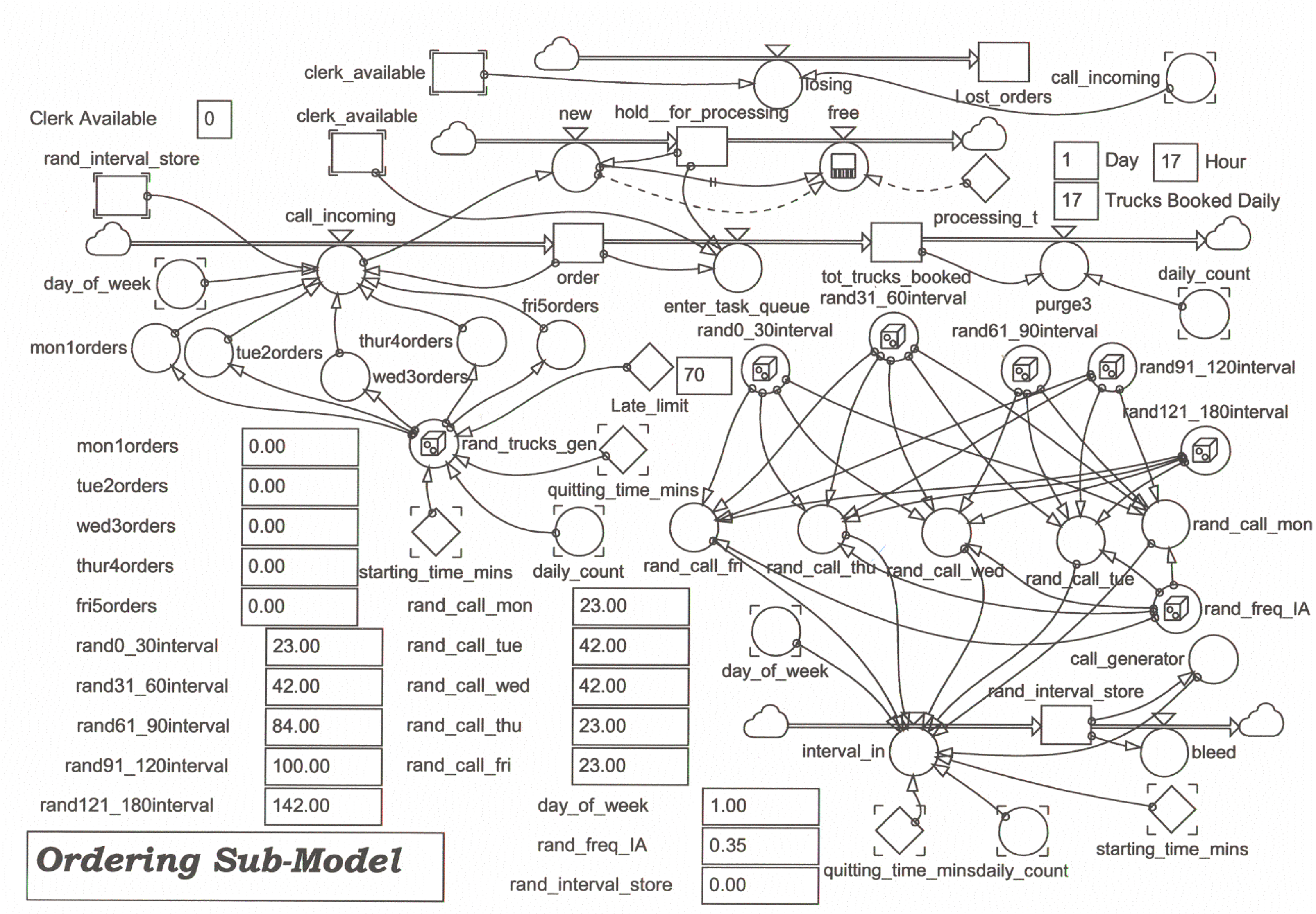
This model has been tested over 40 simulation runs.

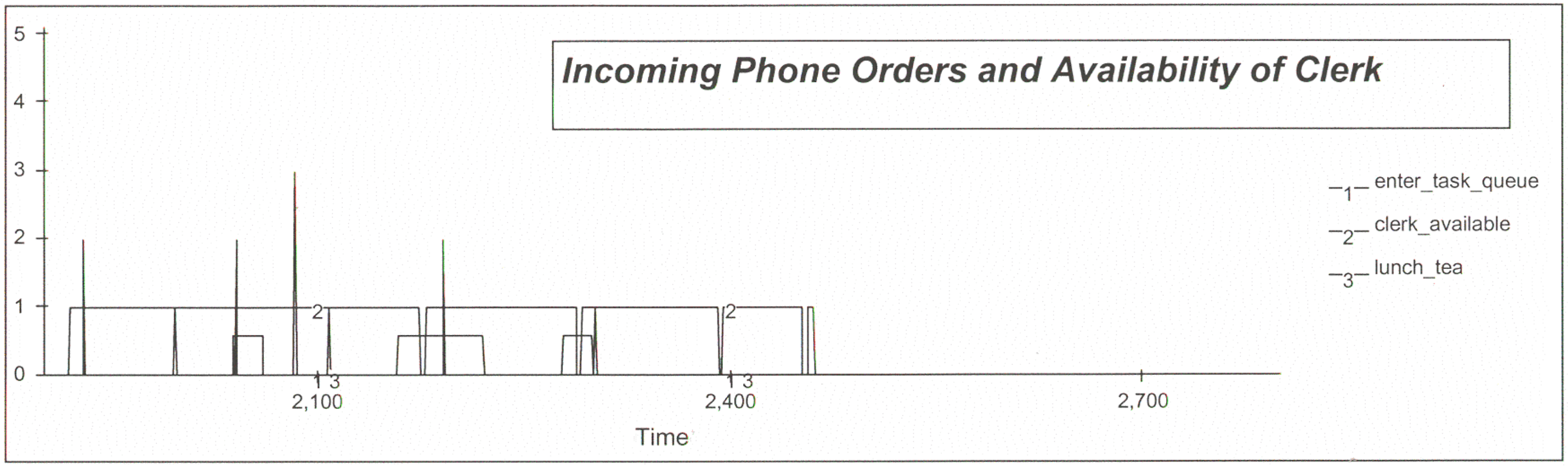
Given that the latest time a truck could be dispatched to deliver concrete was two hours before quitting time, key observations were:
. Unacceptably high levels of lost orders resulted unless a relief was employed to take orders during scheduled breaks taken by the clerk. Because of the 'knock-on effect' on customer confidence resulting from ignored phone calls, it is considered essential to provide a relief for the clerk during scheduled breaks.
. When a relief was provided, lost orders were reduced by approximately one-third but, then, a significant number of orders captured could not be delivered. This was the case for numbers of trucks less than eight. When eight trucks were avaliable, virtually all orders taken could be delivered the same day.
. The impact of 'lost orders' on the business needs further investigation. The sensitivity of customers to having a call unanswered is unclear. It is reasonable to exptect that a customer will call back at least once. If the follow-up call is made a couple of minutes later, then the probability of that call being answered would be high. If that is so, then lost orders for both cases (with or without a relief being provided) are likely to be lower than the model suggests.
. The probability that any driver will miss at least one break (morning tea, lunch, afternoon tea) per day appears to be greater than 50% although this was not specifically measured. This high level of missed breaks would continue to be unacceptable to drivers and their union.

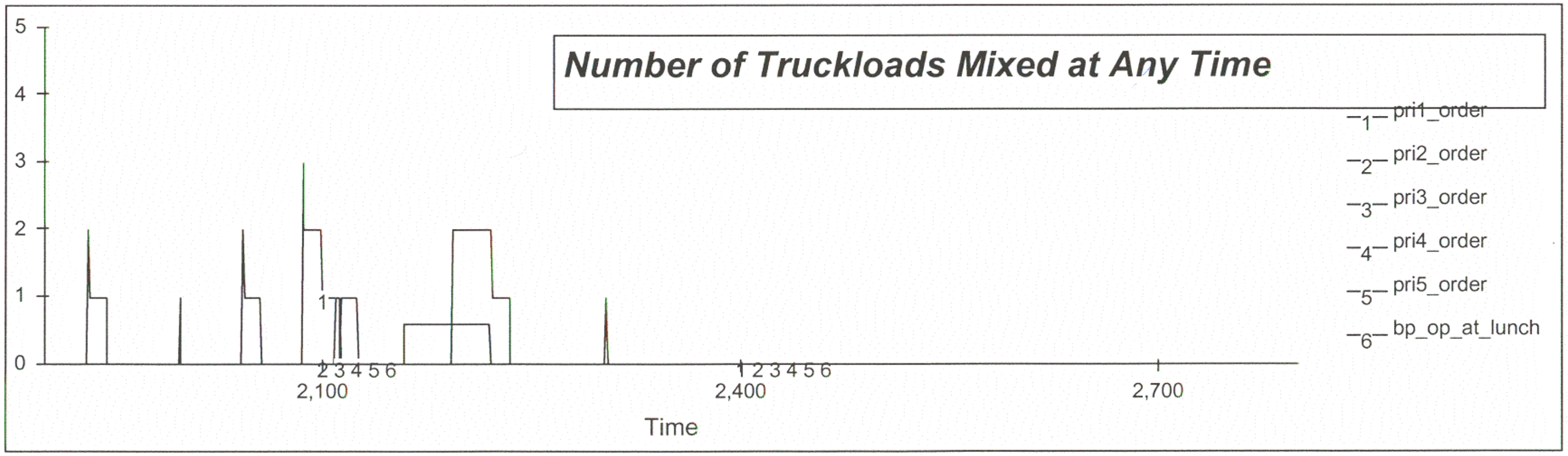
Recommendations are:
. Employ a relief during scheduled breaks taken by clerk. Preferably also provide a relief during unscheduled breaks also (zero lost calls will be the result).
. Five trucks are insuffucient. Six would provide an effective delivery service particularly if lost orders are lower, in practice, than the model suggests. Seven trucks appears to be the optimum number.
. Costs of additional trucks and employment of a 'fill-in' need to be compared with the additional revenue resulting from greater turnover.

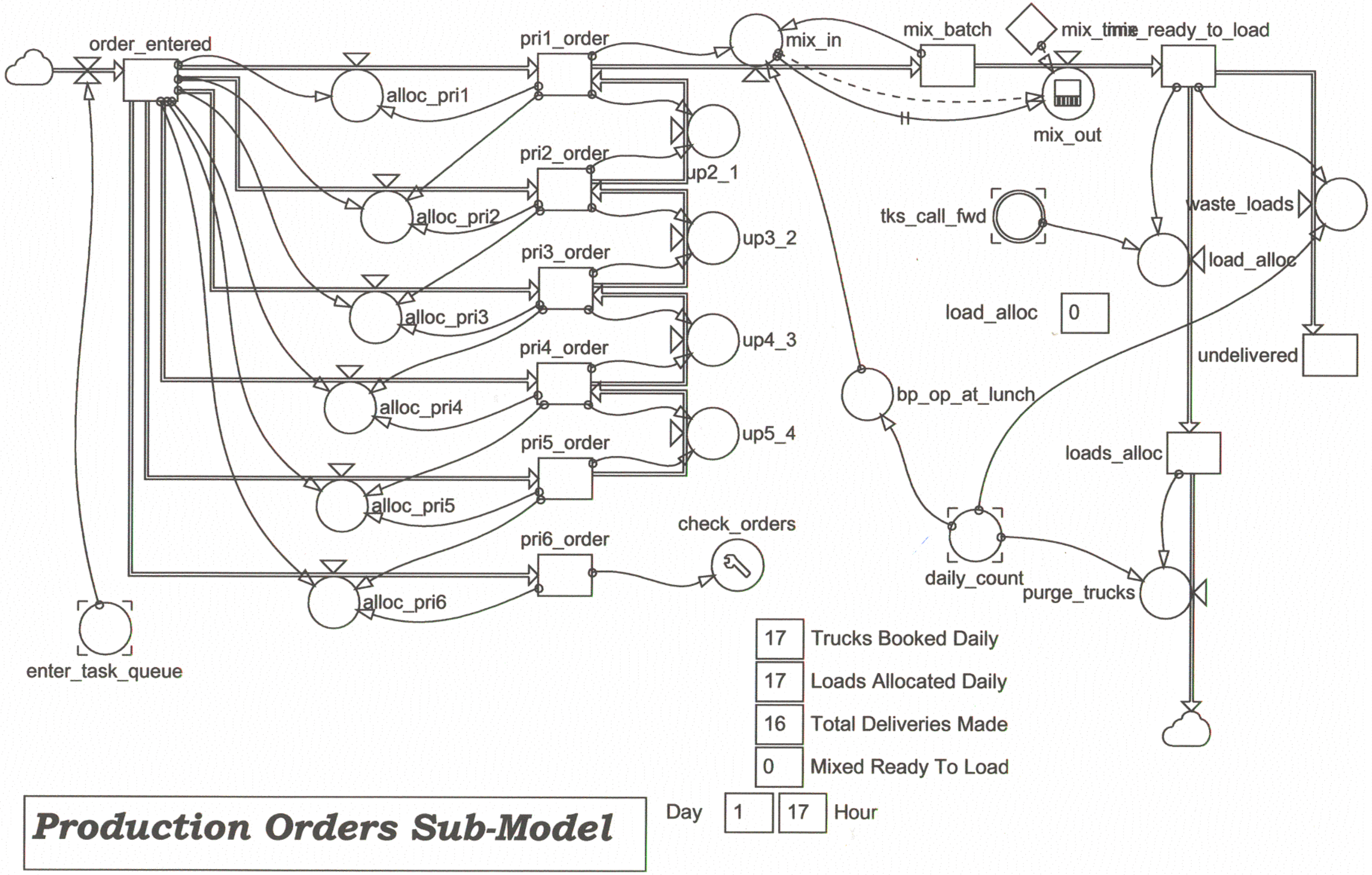

Clerical Office Sub-Model
Clerks_Relief
ready_relief
Daily Count
1070
daily_count
1
work_day_wk_n
elapsed_wks
week_number
Clerk Available
0
breaks
0
breaks
lunch_tea
time_counter
day_of_week
lerk_available
relief_avail
minute_TOD
hour_TOD
clerk_leaving
scheduled_break
random_gen
Week No
1
1
Day of Week
rand
Hours
17
50
Minutes
work_day_wk_n
purge1
clerk_returning
clerk_unavailable
random_break
rand_count
quitting_time_mins
5
break_yes_no
daily_count
to_work
starting_time_mins
break_duration
daily_count
random_period
in_break_count
purge2
1.0
0.8
0.6
0.4
0.2
0.0
2,000
2,500
Time
clerk_available
lunch_tea


The simulation will be paused until:
a. the number of trucks is set to a number greater than zero using this slider bar, and
b. pause button pressed.
Production and Delivery Status
Trucks_Available
0 2 4 6 8
1 2 3 4 5 6 7 8
Week No 1 1 Day of Week
Hours 17 50 Minutes
Daily Count 1070
Clerk Available 0
Lost_orders 3
17 Trucks Booked Daily
0 Mixed Ready to Load
17 Loads Allocated Daily
Total Delivered @ 9pm Daily 0
Total Unable to Deliver @ 9 pm Daily 0
Clerks_Relief
0
0.0 0.4 1.0
70
Minutes before quitting
Late_limi
50 100 150
#2 #3 #4 #5 #6 #7 #8
Parked #1 0 1 1 1 1 1 1 1
Batch Plant 0 0 0 0 0 0 0 0
Loaded/Transit 0 0 0 0 0 0 0 0
Delivering 0 0 0 0 0 0 0 0
Returning/Transit 1 0 0 0 0 0 0 0
Delivered 4 3 3 1 1 2 2 1
Mornos Taken 0 1 1 0 0 0 0 0
Lunch Taken 1 1 1 1 1 0 0 0
Tea Taken 0 1 1 1 1 1 1 0
Hours 17 50 Mins
Simulation time is one week = 10,080 timesteps

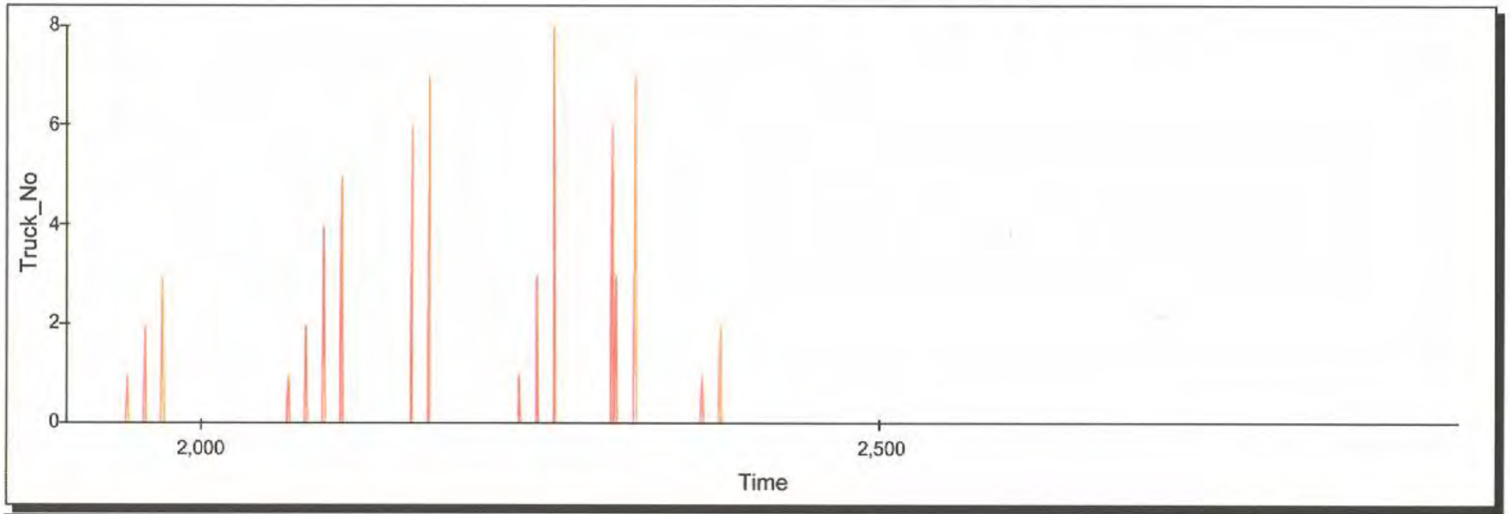

Ordering Sub-Model
Clerk Available 0
clerk_available
rand_interval_store
call_incoming
new
hold__for_processing
free
losing
Lost_orders
1 Day
17 Hour
17 Trucks Booked Daily
processing_t
order
enter_task_queue
tot_trucks_booked
purge3
daily_count
day_of_week
mon1orders
tue2orders
wed3orders
thur4orders
fri5orders
rand_trucks_gen
Late_limit
70
quitting_time_mins
starting_time_mins
rand0_30interval
rand31_60interval
rand61_90interval
rand91_120interval
rand121_180interval
rand_call_mon
rand_call_tue
rand_call_wed
rand_call_thu
rand_call_fri
rand_freq_IA
call_generator
interval_in
bleed
mon1orders 0.00
tue2orders 0.00
wed3orders 0.00
thur4orders 0.00
fri5orders 0.00
rand0_30interval 23.00
rand31_60interval 42.00
rand61_90interval 84.00
rand91_120interval 100.00
rand121_180interval 142.00
rand_call_mon 23.00
rand_call_tue 42.00
rand_call_wed 42.00
rand_call_thu 23.00
rand_call_fri 23.00
day_of_week 1.00
rand_freq_IA 0.35
rand_interval_store 0.00

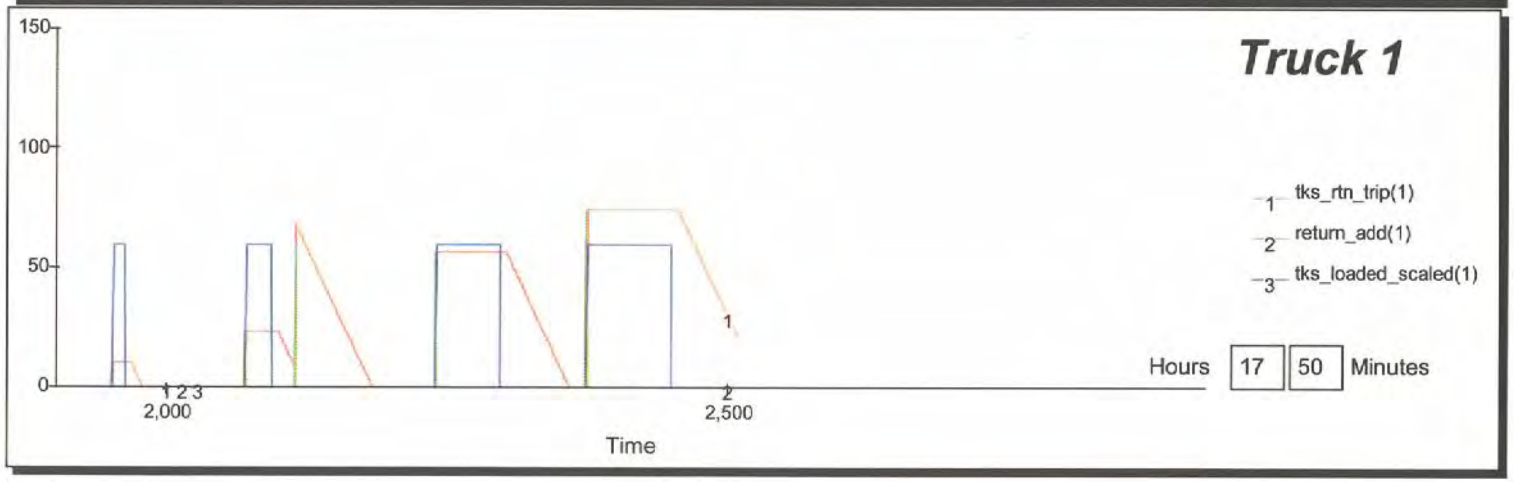

Incoming Phone Orders and Availability of Clerk
1 enter_task_queue
2 clerk_available
3 lunch_tea
0
1
2
3
4
5
2,100
2,400
2,700
Time

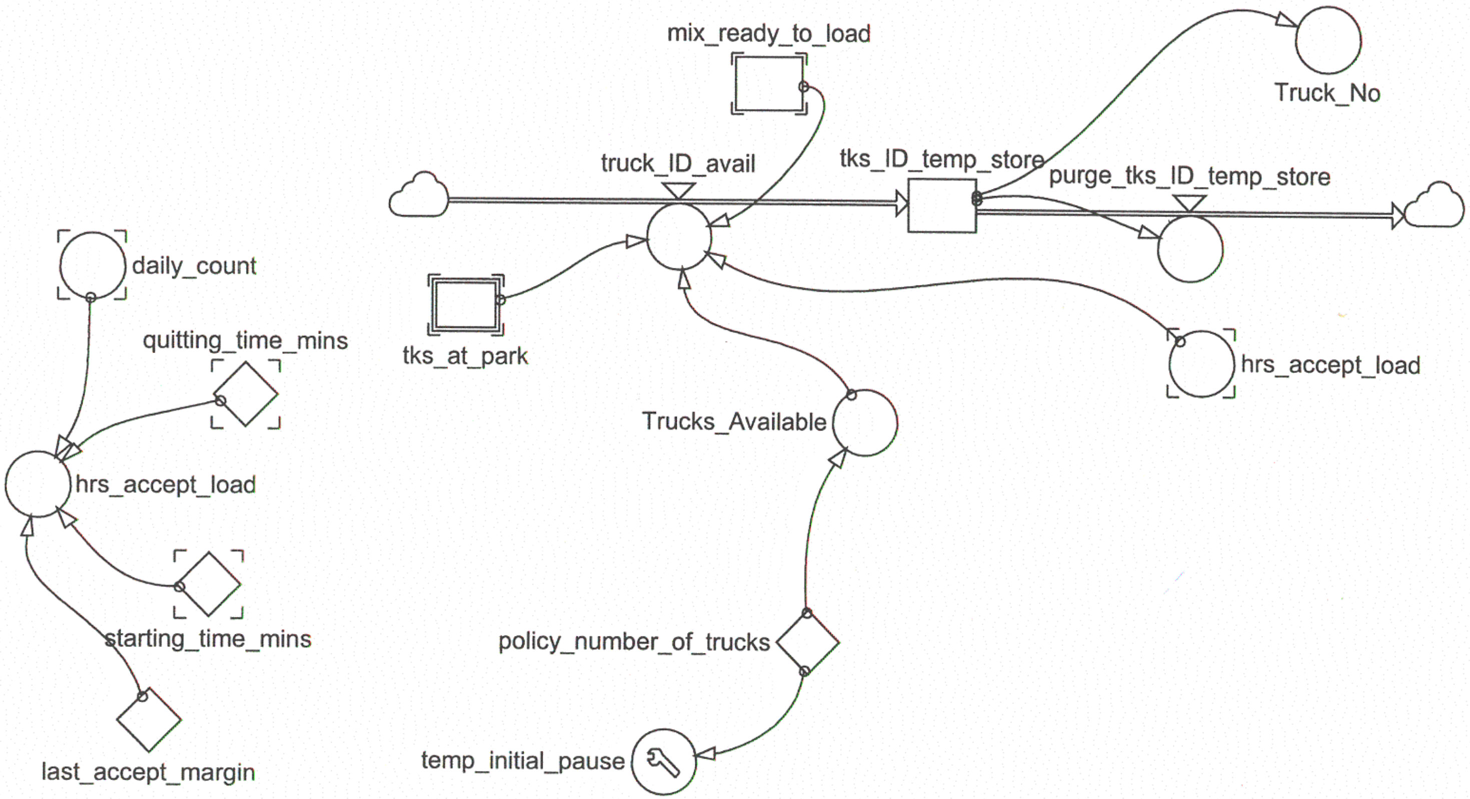

Number of Truckloads Mixed at Any Time
1 pri1_order
2 pri2_order
3 pri3_order
4 pri4_order
5 pri5_order
6 bp_op_at_lunch
0
1
2
3
4
5
2,100
2,400
2,700
Time


order_entered
alloc_pri1
alloc_pri2
alloc_pri3
alloc_pri4
alloc_pri5
alloc_pri6
pri1_order
pri2_order
pri3_order
pri4_order
pri5_order
pri6_order
up2_1
up3_2
up4_3
up5_4
check_orders
enter_task_queue
mix_in
mix_batch
mix_time
mix_ready_to_load
mix_out
tks_call_fwd
waste_loads
load_alloc
load_alloc 0
undelivered
bp_op_at_lunch
loads_alloc
daily_count
purge_trucks
17 Trucks Booked Daily
17 Loads Allocated Daily
16 Total Deliveries Made
0 Mixed Ready To Load
Day 1 17 Hour
Production Orders Sub-Model

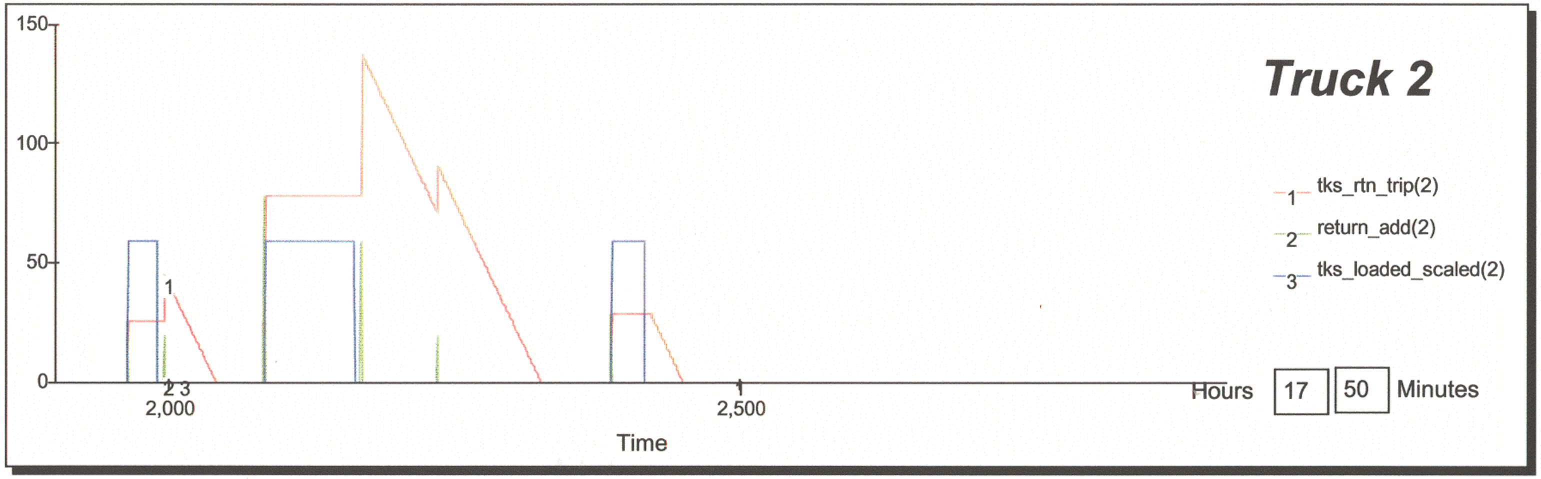
ID Number of Truck Being Tasked

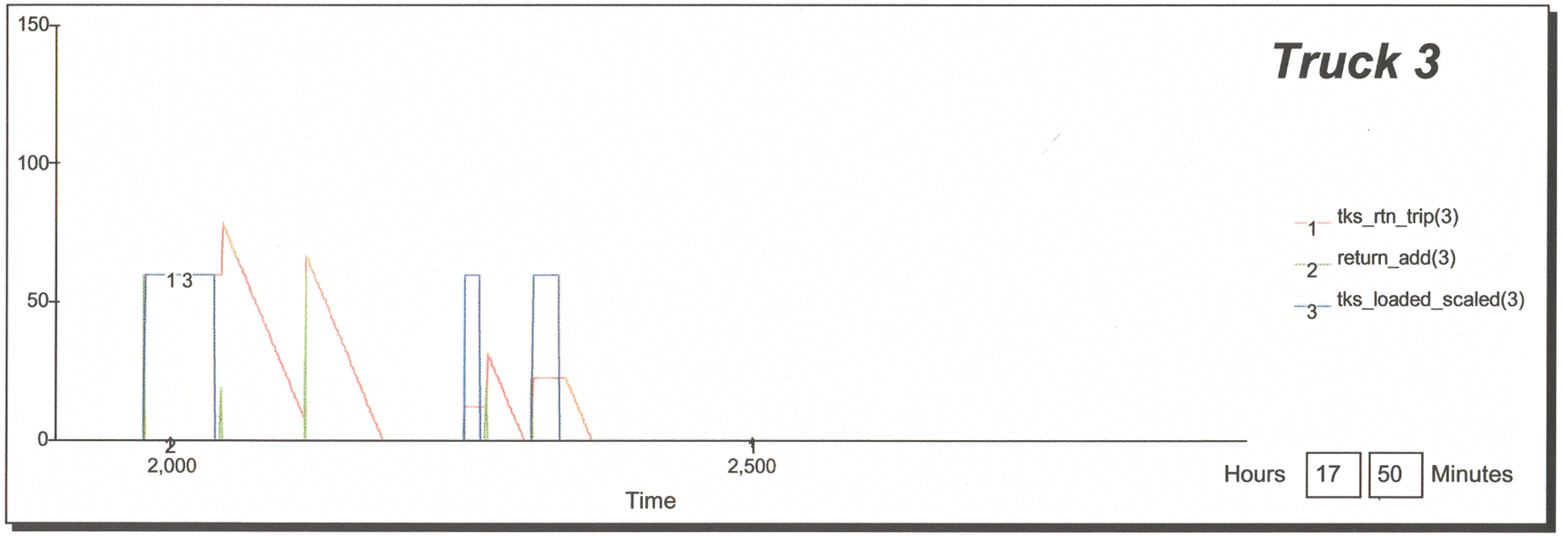


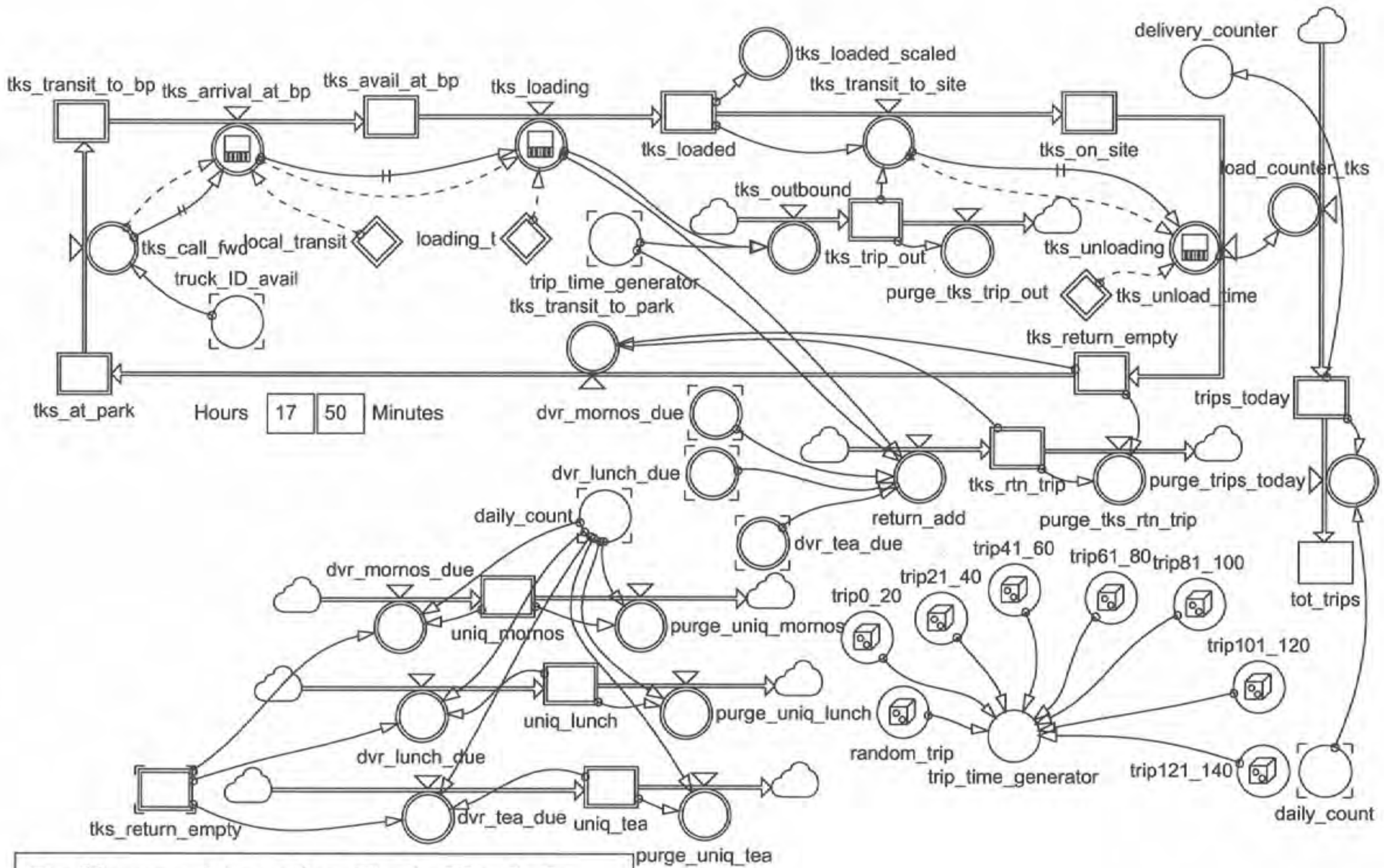




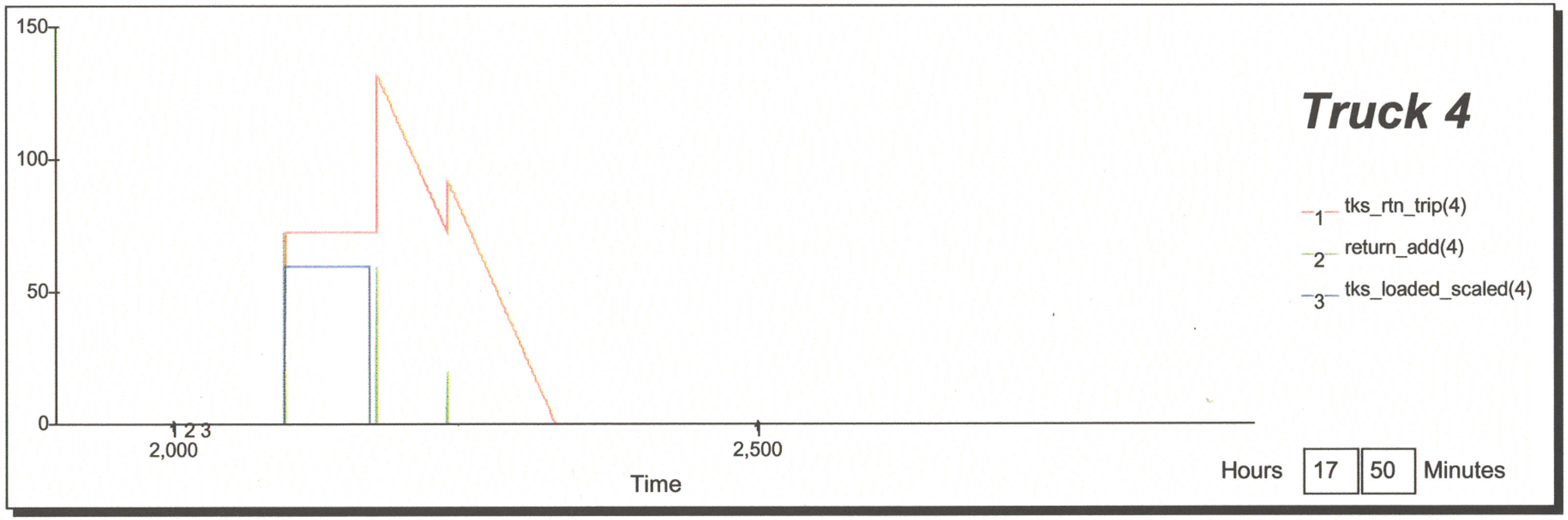
Truck Tasking Sub-Model

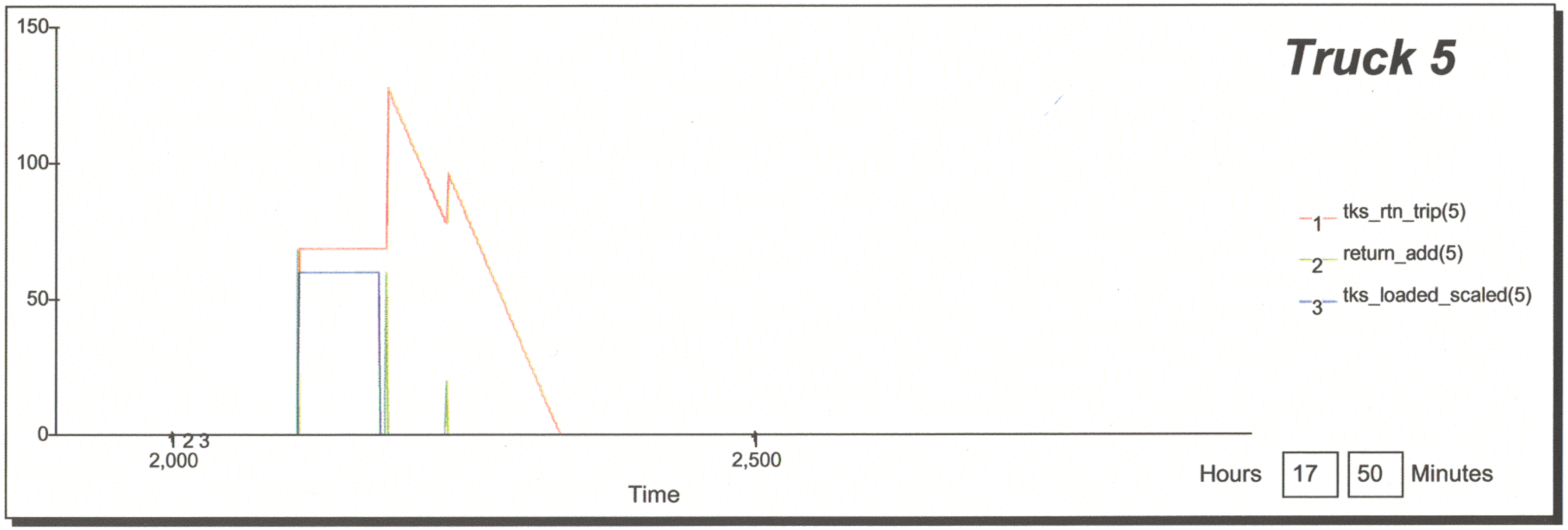

Truck 2
150
100
50
0
2,000
2,500
Time
tks_rtn_trip(2)
return_add(2)
tks_loaded_scaled(2)
Hours
17
50
Minutes

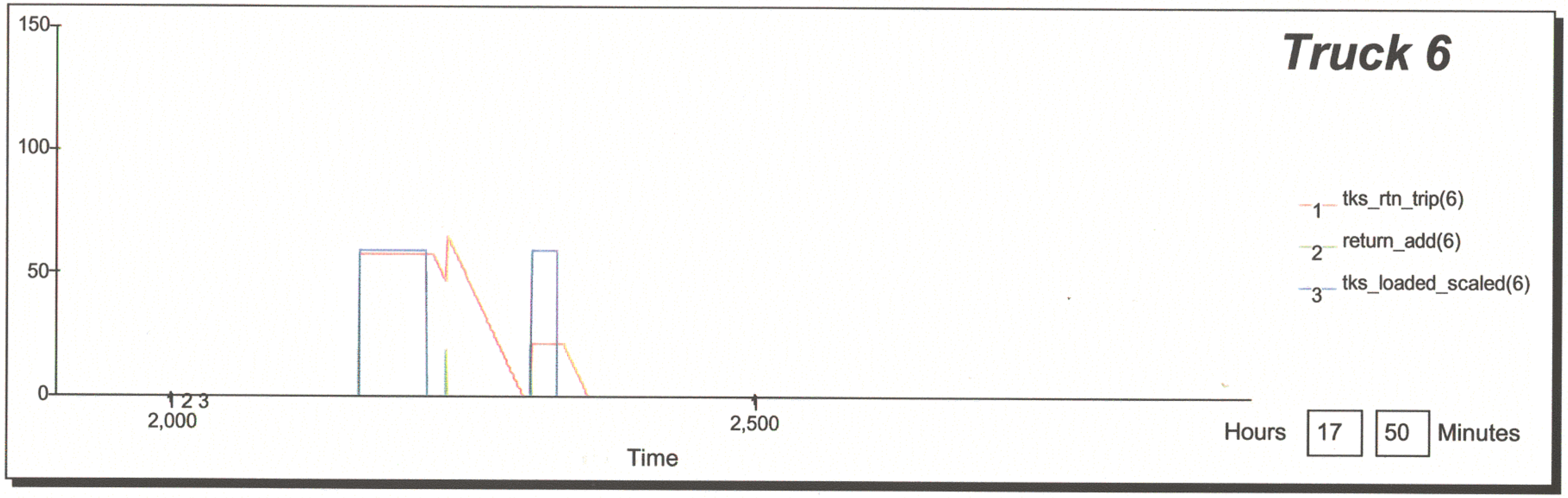

Truck 3
150
100
50
0
2,000
2,500
Time
tks_rtn_trip(3)
return_add(3)
tks_loaded_scaled(3)
Hours
17
50
Minutes

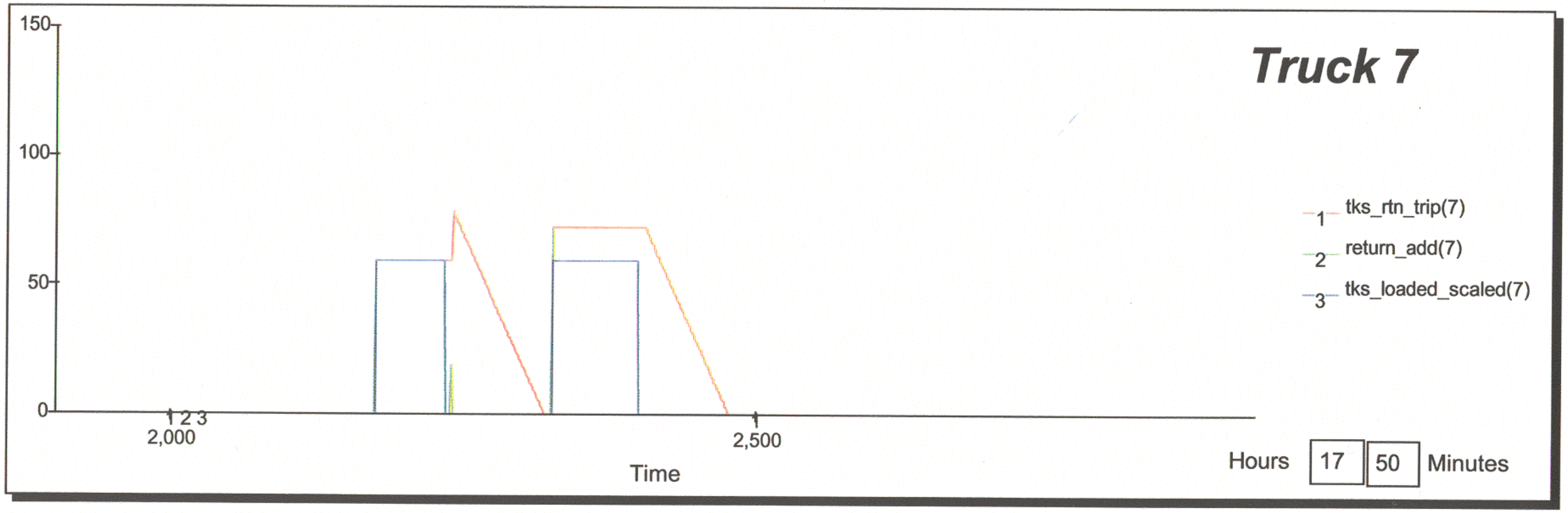


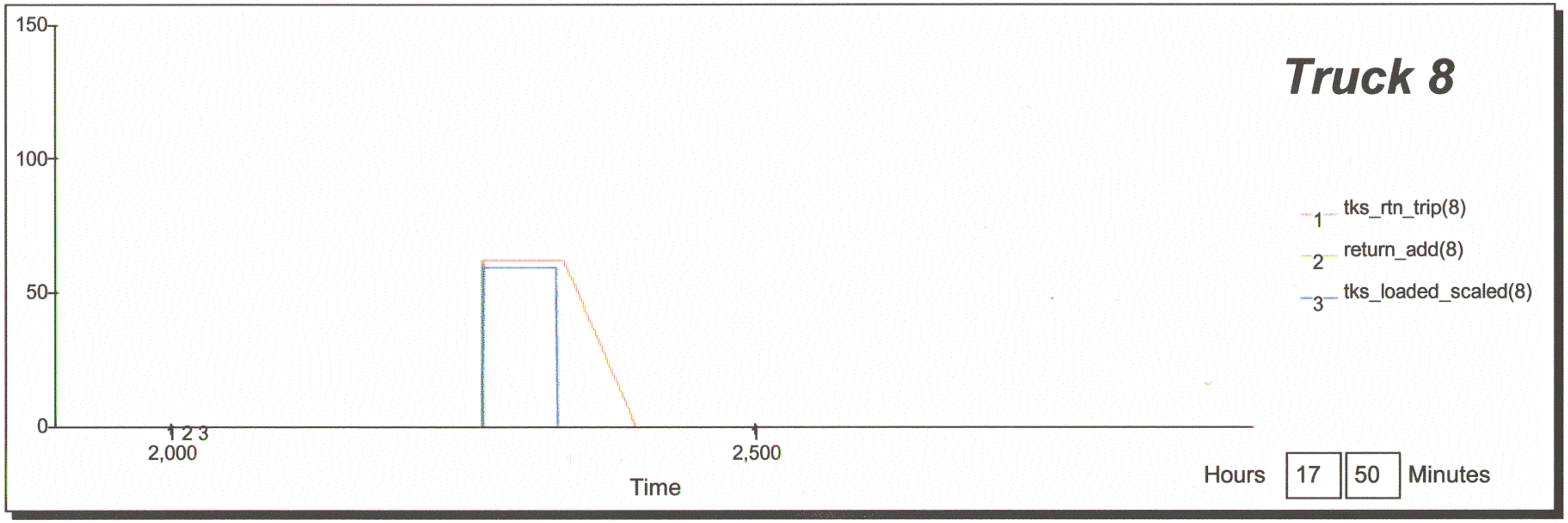
Delivery Trucks Sub-Model


Truck 4
tks_rtn_trip(4)
return_add(4)
tks_loaded_scaled(4)
150
100
50
0
2,000
2,500
Time
Hours 17 50 Minutes


Truck 5
tks_rtn_trip(5)
return_add(5)
tks_loaded_scaled(5)
150
100
50
0
2,000
2,500
Time
Hours 17 50 Minutes


Truck 6
150
100
50
0
2,000
2,500
Time
1 tks_rtn_trip(6)
2 return_add(6)
3 tks_loaded_scaled(6)
Hours 17 50 Minutes


Truck 7
150
100
50
0
2,000
2,500
Time
1 tks_rtn_trip(7)
2 return_add(7)
3 tks_loaded_scaled(7)
Hours 17 50 Minutes


Truck 8
150
100
50
0
2,000
2,500
Time
1 tks_rtn_trip(8)
2 return_add(8)
3 tks_loaded_scaled(8)
Hours
17
50
Minutes

break_duration
INIT 0
-dt*purge2
+dt*in_break_count

clerk_available
INIT 0
+dt*clerk_returning
-dt*clerk_leaving

clerk_unavailable
INIT 1
-dt*clerk_returning
+dt*clerk_leaving

hold__for_processing
INIT 0
-dt*free
+dt*new

loads_alloc
INIT 0
-dt*purge_trucks
+dt*load_alloc

Lost_orders
INIT 0
+dt*losing

mix_batch
INIT 0
-dt*mix_out
+dt*mix_in

mix_ready_to_load
INIT 0
-dt*waste_loads
-dt*load_alloc
+dt*mix_out

order
INIT 0
+dt*call_incoming
-dt*enter_task_queue

order_entered
INIT 0
-dt*alloc_pri6
-dt*alloc_pri1
-dt*alloc_pri4
-dt*alloc_pri5
-dt*alloc_pri3
-dt*alloc_pri2
+dt*enter_task_queue
Additional capacity has been added to the model for future expansion to handle orders held over from one day to the next.

pri1_order
INIT 0
+dt*up2_1
-dt*mix_in
+dt*alloc_pri1

pri2_order
INIT 0
+dt*up3_2
-dt*up2_1
+dt*alloc_pri2

pri3_order
INIT 0
+dt*up4_3
-dt*up3_2
+dt*alloc_pri3

pri4_order
INIT 0
+dt*up5_4
-dt*up4_3
+dt*alloc_pri4

pri5_order
INIT 0
-dt*up5_4
+dt*alloc_pri5

pri6_order
INIT 0
+dt*alloc_pri6

rand_count
INIT 0
-dt*purge1
+dt*rand

rand_interval_store
INIT 0
-dt*bleed
+dt*interval_in

tks_at_park
T=1..9
INIT 1
-dt*tks_call_fwd
+dt*tks_transit_to_park
Trucks #1 through #9 are all initially avaliable at work start time.

tks_avail_at_bp
T=1..9
INIT 0
+dt*tks_arrival_at_bp
-dt*tks_loading

tks_ID_temp_store
INIT 0
-dt*purge_tks_ID_temp_store
+dt*truck_ID_avail

tks_loaded
T=1..9
INIT 0
+dt*tks_loading
-dt*tks_transit_to_site

tks_on_site
T=1..9
INIT 0
-dt*tks_unloading
+dt*tks_transit_to_site

tks_return_empty
T=1..9
INIT 0
+dt*tks_unloading
-dt*tks_transit_to_park

tks_rtn_trip
T=1..9
0
-dt*purge_tks_rtn_trip
+dt*return_add

tks_transit_to_bp
T=1..9
0
-dt*tks_arrival_at_bp
+dt*tks_call_fwd

tks_trip_out
T=1..9
0
-dt*purge_tks_trip_out
+dt*tks_outbound

tot_trips
0
+dt*ARRSUM(purge_trips_today)
Total trips calculated as at 2100 hrs daily.

tot_trucks_booked
0
-dt*purge3
+dt*enter_task_queue

trips_today
T=1..9
0
-dt*purge_trips_today
+dt*load_counter_tks

undelivered
0
+dt*waste_loads

uniq_lunch
T=1..9
0
-dt*purge_uniq_lunch
+dt*dvr_lunch_due

uniq_mornos
T=1..9
0
-dt*purge_uniq_mornos
+dt*dvr_mornos_due

uniq_tea
T=1..9
0
-dt*purge_uniq_tea
+dt*dvr_tea_due

alloc_pri1
= PULSEIF((order_entered>0) AND (pri1_order=0) , order_entered)

alloc_pri2
= PULSEIF((order_entered>0) AND (pri2_order=0) AND (pri1_order>0) , order_entered)

alloc_pri3
= PULSEIF((order_entered>0) AND (pri3_order=0) AND (pri2_order>0) , order_entered)

alloc_pri4
= PULSEIF((order_entered>0) AND (pri4_order=0) AND (pri3_order>0) , order_entered)

alloc_pri5
= PULSEIF((order_entered>0) AND (pri5_order=0) AND (pri4_order>0) , order_entered)

alloc_pri6
= PULSEIF((order_entered>0) AND (pri6_order=0) AND (pri5_order>0) , order_entered)

bleed
= PULSEIF(rand_interval_store>=1 , 1)

call_incoming
= ((IF(day_of_week=1, mon1orders, 0)+IF(day_of_week=2, tue2orders, 0)+IF(day_of_week=3, wed3orders, 0)+IF(day_of_week=4, thur4orders, 0)+IF(day_of_week=5, fri5orders, 0))*PULSEIF(rand_interval_store=0 , 1))*IF(order>0, 0, 1)

clerk_leaving
= IF(clerk_available=1, clerk_available, 0)*(scheduled_break)+IF(daily_count>quitting_time_mins, clerk_available,0)

For the clerk to be able to take a break, he must be at work. 'scheduled_on_work_day' is a YES/NO, boolean function The breaks he takes is the totality of scheduled breaks and random (unscheduled breaks).

clerk_returning
= IF(clerk_unavailable=1, clerk_unavailable, 0)*to_work

dvr_lunch_due
T=1..9
= PULSEIF((daily_count>=675) AND (daily_count<=780),1)*IF(tks_return_empty=1, 1, 0)*IF(uniq_lunch>=1, 0, 1)

dvr_mornos_due
T=1..9
= PULSEIF((daily_count>=555) AND (daily_count<=620),1)*IF(tks_return_empty=1, 1, 0)*IF(uniq_mornos>=1, 0, 1)
dvr_tea_due
T=1..9
= PULSEIF((daily_count>=795) AND (daily_count<=860), 1)*IF(tks_return_empty=1, 1, 0)*IF(uniq_tea>=1, 0, 1)
enter_task_queue
= IF((order>0) , order,0)*IF(hold__for_processing>0, 0, 1)*IF(clerk_available=1, 1, 0)
This version of the model does not provide for orders to be taken after 1630 or for subsequent days. It is assumed that all orders placed on a given day must be processed and delivery completed that day.
free
= DELAYPPL(new, processing_t)
in_break_count
= break_yes_no*random_period
interval_in
= IF(call_generator=1, 1, 0)*(IF(day_of_week=1, rand_call_mon, 0)+IF(day_of_week=2, rand_call_tue, 0)+IF(day_of_week=3, rand_call_wed, 0)+IF (day_of_week=4, rand_call_thu, 0)+IF(day_of_week=5, rand_call_fri, 0))*IF(daily_count<(starting_time_mins-1), 0, 1)*IF(daily_count> (quitting_time_mins-30), 0, 1)
The idea is to generate a random inter-call time and store it at the time a call occurs, then count this down to generate the next call. Calls are generated from 1 min before starting time (ie, first call can arrive at starting time) and calls for delivery today are not taken from 30 mins before quitting.
load_alloc
= IF(mix_ready_to_load>0 ,1, 0)*PULSEIF((tks_call_fwd(1)=1), 1) OR IF(mix_ready_to_load>0, 1, 0)*PULSEIF(tks_call_fwd(2)=1, 1) OR IF (mix_ready_to_load>0, 1, 0)*PULSEIF(tks_call_fwd(3)=1 ,1) OR IF(mix_ready_to_load>0, 1, 0)*PULSEIF(tks_call_fwd(4)=1, 1) OR IF(mix_ready_tc
load_counter_tks
T=1..9
= PULSEIF(tks_unloading=1 , 1)
losing
= IF((clerk_available=0)AND(call_incoming>0), call_incoming, 0)
mix_in
= PULSEIF(pri1_order>0 , 1)*IF(mix_batch=0, 1, 0)*IF(bp_op_at_lunch>0, 0, 1)
mix_out
= DELAYPPL(mix_in, mix_time)
new
= IF(call_incoming>0, 1, 0)*IF(hold__for_processing>0, 0, 1)
purge_tks_ID_temp_store
= IF(tks_ID_temp_store>0, tks_ID_temp_store, 0)

purge_tks_rtn_trip
T=1..9
= PULSEIF((tks_rtn_trip>=1) AND (tks_return_empty>=1) , 1)
purge_tks_trip_out
T=1..9
= PULSEIF(tks_trip_out>=1 , 1)
purge_trips_today
T=1..9
= IF(daily_count>21*60, trips_today, 0)
purge_trucks
= PULSEIF(daily_count>=23*60 , loads_alloc)
At 2300 hrs daily, the level 'tot_trucks_loaded' is purged.
purge_uniq_lunch
T=1..9
= IF(daily_count>23*60, uniq_lunch,0)
purge_uniq_mornos
T=1..9
= IF(daily_count>23*60, uniq_mornos,0) + IF(uniq_mornos>=1, uniq_mornos-1, 0)
purge_uniq_tea
T=1..9
= IF(daily_count>23*60 , uniq_tea,0)
purge1
= IF((daily_count>60*23), rand_count, 0)
After 1800 hrs daily, 'rand_count' is purged.
purge2
= IF(break_duration>=1, 1, 0)
purge3
= IF((daily_count>=60*23), tot_trucks_booked, 0)
rand
= IF(random_break=1, 1, 0)
return_add
T=1..9
= PULSEIF(tks_loading(T)=1, INT(trip_time_generator/2)) + IF(dvr_mornos_due(T)=1, 20, 0) + IF(dvr_lunch_due(T)=1, 60, 0) + IF(dvr_tea_due(T)=1, 20, 0) WHEN T>0
It is assumed that each driver will take mornos, lunch, or tea break at the first opportunity that presents.
tks_arrival_at_bp
T=1..9
= DELAYPPL(tks_call_fwd(T), local_transit) WHEN T>0

tks_call_fwd
T=1..9
= IF((truck_ID_avail=0.1),1,0) WHEN T=1 BUT IF((truck_ID_avail=0.2),1,0) WHEN T=2 BUT IF((truck_ID_avail=0.3),1,0) WHEN T=3 BUT IF(
(truck_ID_avail=0.4),1,0) WHEN T=4 BUT IF((truck_ID_avail=0.5),1,0) WHEN T=5 BUT IF((truck_ID_avail=0.6),1,0) WHEN T=6 BUT IF(
(truck_ID_avail=0.7),1,0) WHEN T=7 BUT IF((truck_ID_avail=0.8),1,0) WHEN T=8 BUT IF((truck_ID_avail=0.9),1,0) WHEN T=9
Driver can only be asked to commence
delivery cycle if sufficient time exists. That is there is no point loading a truck to satisfy an order to be delivered 20 kilometres away when it is five m

tks_loading
T=1..9
= DELAYPPL(tks_arrival_at_bp(T), loading_t) WHEN T>0

tks_outbound
T=1..9
= PULSEIF(tks_loading=1,INT(trip_time_generator/2))

tks_transit_to_park
T=1..9
= PULSEIF(tks_rtn_trip(T)=1 , tks_return_empty(T)) WHEN T>0

tks_transit_to_site
T=1..9
= PULSEIF(tks_trip_out(T)=1 ,tks_loaded(T)) WHEN T>0

tks_unloading
T=1..9
= DELAYPPL(tks_transit_to_site(T), tks_unload_time(T)) WHEN T>0

truck_ID_avail
= IF(SCANEQ(tks_at_park,1)>8,0,1)*(SCANEQ(tks_at_park,1))*IF(hrs_accept_load=1,1,0)*IF
(mix_ready_to_load>0,1,0)*0.1*IF
(SCANEQ(tks_at_park,1)>Trucks_Available,0,1)
Although there are nine array elements,
only the first eight are used to represent trucks. If the ninth array element is found by SCANEQ to be zero, an indeterminate result is returned. To a

up2_1
= IF((pri1_order=0) AND (pri2_order>0), pri2_order, 0)

up3_2
= IF((pri2_order=0) AND (pri3_order>0), pri3_order, 0)

up4_3
= IF((pri3_order=0) AND (pri4_order>0), pri3_order, 0)

up5_4
= IF((pri4_order=0) AND (pri5_order>0), pri5_order, 0)

waste_loads
= IF(daily_count>=21*60, mix_ready_to_load, 0)
Each day at 2100 hra loads not able to be delivered are calculated.

bp_op_at_lunch
= IF(daily_count>=719, 1, 0)*IF(daily_count<=780, 1, 0)*0.6
Scaling factor of 0.6 is applied solely for the purpose of graphing the availbility of the operator on the same graph as a selection of other variables.

break_yes_no
= IF(rand_count<6, 1, 0)*random_break

breaks
= IF((daily_count>=599) AND (daily_count<=620), 1,0)+IF((daily_count>=719) AND (daily_count<=780), 1, 0)+IF((daily_count>=839) AND (daily_count <=860), 1, 0)

call_generator
= IF(rand_interval_store>0, 0, 1)

check_orders
= STOPIF(pri6_order>0)

Clerks_Relief
= INT(ready_relief)
Value one or zero.

daily_count
= (time_counter MOD 1440)*IF(work_day_wk_n>=1, 1, 0)

day_of_week
= INT((time_counter/1440) MOD 7)

delivery_counter
= ARRSUM(trips_today)

elapsed_wks
= INT(time_counter/10080)

fri5orders
= IF((rand_trucks_gen>0) AND (rand_trucks_gen<=0.143), 1, 0)+IF((rand_trucks_gen>0.143) AND(rand_trucks_gen<=0.286), 2, 0)+IF((rand_trucks_gen>0.286) AND (rand_trucks_gen<=0.429), 3, 0)+IF((rand_trucks_gen>0.429) AND (rand_trucks_gen<=0.857), 4, 0)+IF((rand_trucks_gen>0.857) AND(rand_trucks_gen<=1.000), 5, 0)

hour_TOD
= INT((time_counter/60) MOD 24)

hrs_accept_load
= IF(daily_count>=starting_time_mins, 1, 0)*IF(daily_count<=(quitting_time_mins-last_accept_margin), 1, 0)
'0.1' is used to identify truck No. 1, etc.

lunch_tea
= breaks*0.6
This auxiliary provides a graphing facility for scheduled breaks

minute_TOD
= INT(time_counter MOD 60)

mon1orders
= IF((rand_trucks_gen>0) AND (rand_trucks_gen<0.273),1,0)+IF((rand_trucks_gen>=0.273) AND (rand_trucks_gen<0.636), 2, 0)+IF((rand_trucks_gen >=0.636) AND (rand_trucks_gen<0.909), 3, 0)+IF((rand_trucks_gen>=0.909) AND (rand_trucks_gen<=1.000), 4, 0)

rand_call_fri
= IF((rand_freq_IA>=0.000) AND (rand_freq_IA<0.429), rand0_30interval, 0)+IF((rand_freq_IA>=0.429) AND (rand_freq_IA<0.571), rand31_60interval, 0)+IF((rand_freq_IA>=0.571) AND (rand_freq_IA<0.857), rand91_120interval, 0)+IF((rand_freq_IA>=0.857) AND (rand_freq_IA <=1.000), rand121_180interval, 0)

rand_call_mon
= IF((rand_freq_IA>=0.000) AND (rand_freq_IA<0.364), rand0_30interval, 0)+IF((rand_freq_IA>=0.364) AND (rand_freq_IA<0.636), rand31_60interval, 0)+IF((rand_freq_IA>=0.636) AND (rand_freq_IA<0.909), rand61_90interval, 0)+IF((rand_freq_IA>=0.909) AND (rand_freq_IA< =1.000), rand91_120interval,0)

rand_call_thu
= IF((rand_freq_IA>=0.000) AND (rand_freq_IA<0.429), rand0_30interval, 0)+IF((rand_freq_IA>=0.429) AND (rand_freq_IA<0.571), rand31_60interval, 0)+IF((rand_freq_IA>=0.571) AND (rand_freq_IA<0.714), rand91_120interval, 0)+IF((rand_freq_IA>=0.714) AND (rand_freq_IA <=1.000), rand121_180interval, 0)

rand_call_tue
= IF((rand_freq_IA>=0) AND (rand_freq_IA<0.429), rand31_60interval, 0)+IF((rand_freq_IA>=0.429) AND (rand_freq_IA<0.714), rand61_90interval, 0) +IF((rand_freq_IA>=0.714) AND (rand_freq_IA<0.857), rand91_120interval, 0)+IF((rand_freq_IA>=0.857) AND (rand_freq_IA<=1.000), rand121_180interval, 0)

rand_call_wed
= IF((rand_freq_IA>=0.000) AND (rand_freq_IA<0.333), rand0_30interval, 0)+IF((rand_freq_IA>=0.333) AND (rand_freq_IA<0.500), rand31_60interval, 0)+IF((rand_freq_IA>=0.500) AND (rand_freq_IA<0.667), rand61_90interval, 0)+IF((rand_freq_IA>=0.667) AND (rand_freq_IA< =1.000), rand121_180interval, 0)

rand_freq_IA
= RANDOM(0,1.000)

rand_trucks_gen
= RANDOM(0,1)*IF(daily_count<(starting_time_mins-1),0,1)*IF(daily_count>(quitting_time_mins-Late_limit), 0, 1)
Orders are not taken after "ordering_ time_ limit" in minutes before quitting time. This time may be set by management policy

rand0_30interval
= INT(RANDOM(0,30))

rand121_180interval
= INT(RANDOM(121,180))

rand31_60interval

= INT(RANDOM(31,60))

rand61_90interval

= INT(RANDOM(61,90))

rand91_120interval

= INT(RANDOM(91,120))

random_break

= IF(random_gen>0.987, 1, 0)

random_gen

= IF(scheduled_break=0, 1, 0)*RANDOM(0,1)*IF(daily_count>starting_time_mins, 1, 0)*IF(daily_count<quitting_time_mins, 1, 0)*IF(work_day_wk_n>= 1, 1, 0)

Random number are generated only on working days (days_in_later_weeks >= 1) and during working hours (starting_time < daily_count< quitting_time).

random_period

= INT(RANDOM(3,5))

random_trip

= RANDOM(0,1)

relief_avail

= IF((ready_relief>0)AND(daily_count>8*60)AND(daily_count<17*60), 0, breaks)

This auxiliary allows for a policy to make avaliable a ready relief for morning tea, lunch and afternoon tea breaks taken by clerk. This ready relief may be the site supervisor or manager.

scheduled_break

= IF(break_duration>=1, 1, relief_avail)

temp_initial_pause

= PAUSEIF(policy_number_of_trucks=0)

The simulation will be paused until a number of trucks is selected.

thur4orders

= IF((rand_trucks_gen>0) AND (rand_trucks_gen<0.143), 1, 0)+IF((rand_trucks_gen>=0.143) AND (rand_trucks_gen<0.286), 2, 0)+IF((rand_trucks_gen>=0.286) AND (rand_trucks_gen<0.571), 3, 0)+IF((rand_trucks_gen>=0.571) AND (rand_trucks_gen<=1.000), 4, 0)

time_counter

= TIME

tks_loaded_scaled

T=1..9

= tks_loaded(T)*(60) WHEN T>0

to_work

= IF(daily_count>=(starting_time_mins-1) ,1, 0)*IF(daily_count>=quitting_time_mins, 0, 1)*IF(scheduled_break>=1, 0, 1) trip_time_generator

= INT(IF((random_trip>=0) AND (random_trip<=0.009), trip0_20, 0)+IF((random_trip>0.009) AND (random_trip<=0.135), trip21_40, 0)+IF((random_trip >0.135) AND (random_trip<=378), trip41_60, 0)+IF((random_trip>0.378) AND (random_trip<=0.739), trip61_80, 0)+IF((random_trip>0.739) AND (random_trip<=0.928), trip81_100,0)+IF((random_trip>0.928) AND (random_trip<=0.982), trip101_120, 0)+IF((random_trip>0.982) AND (random_trip<=1.000), trip121_140, 0))

trip0_20

= RANDOM(0,20)

trip101_120

= RANDOM(101,120)

trip121_140

= RANDOM(121,140)

trip21_40

= RANDOM(21,40)

trip41_60

= RANDOM(41,60)

trip61_80

= RANDOM(61,80)

trip81_100

= RANDOM(81,100)

Truck_No

= 10*tks_ID_temp_store

Trucks_Available

= INT(policy_number_of_trucks)

tue2orders

= IF((rand_trucks_gen>0.000) AND (rand_trucks_gen<0.143), 1, 0)+IF((rand_trucks_gen>=0.143) AND (rand_trucks_gen<0.286),2,0)+IF((rand_trucks_gen>=0.286) AND (rand_trucks_gen<0.714), 3, 0)+IF((rand_trucks_gen>=0.714) AND (rand_trucks_gen<=1.000), 4, 0)

wed3orders

= IF((rand_trucks_gen>0.000) AND (rand_trucks_gen<0.167), 2, 0)+IF((rand_trucks_gen>=0.167) AND (rand_trucks_gen<0.333), 3, 0)+IF((rand_trucks_gen>=0.333) AND (rand_trucks_gen<0.667), 4, 0)+IF((rand_trucks_gen>=0.667) AND (rand_trucks_gen<=1.00), 5, 0)

week_number

= elapsed_wks+1

work_day_wk_n

= IF((day_of_week>=1) AND (day_of_week<=5), 1, 0)*IF((elapsed_wks>1), (elapsed_wks), 1)

last_accept_margin

= 30

This is the margin (in minutes) before quitting time, after which orders will not be accepted for delivery today.

Late_limit

= 120

Orders are not taken for the set number of minutes before nominal quiting time.

loading_t

T=1..9

= 4

This is the time taken to load each truck. Four minutes is considered the norm.

local_transit

T=1..9

= 2

Assume mean time to travel from park to batch plant of 2 mins, and is the same for each truck.

mix_time

= 12

This is the time taken to mix a batch of concrete; historically 10 minutes plus two mins contingency. In the absence detailed statistics, it is assumed that there is little variability in the process through breakdowns and the like.

policy_number_of_trucks

= 0

This is a management selectable number of trucks up to a maximum of eight. This number must be an integer.

processing_t

= 10

quitting_time_mins

= 17*60

Quitting time for clerk is 1500 hrs. Current business rules do not accommodate taking orders for the subsequent days.

ready_relief

= 0

This is a management policy decision to make available a ready relief for the clerk during scheduled breaks. Default is zero.

starting_time_mins

= 480

tks_unload_time

T=1..9

= 5

The mean time to unload is assumed to be five minutes. It is assumed that each truck takes the same time to unload.

ANNEX C: PERFORMANCE REPORTING AND EVALUATION CONCEPTUAL MODEL

Title: Project Reporting and Evaluation - Version 4
Filename: C:\WINNT\Profiles\ALANMC ~1\Desktop\ALAN\Latest\Fi
Author: ALAN McLUCAS

Description

The purpose of this model is to demonstrate the importance of minimising performance monitoring and reporting delays, when tracking the progress of projects.

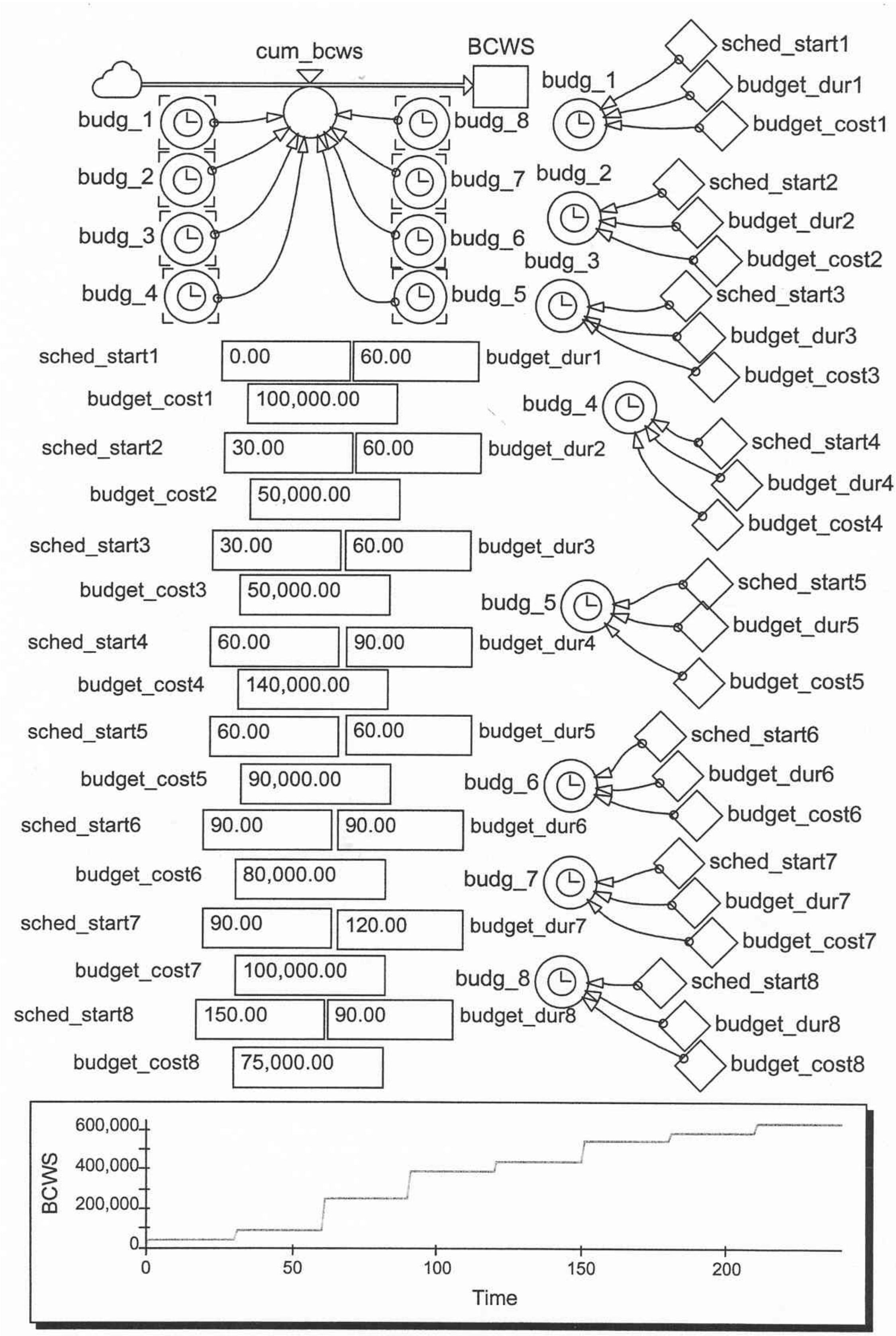
Budgeted Cost of Work Scheduled (BCWS) can be graphed once the project schedule is finalisated, before the project even starts. BCWS becomes the project baseline, against which project performance is reported and monitored.

Budgeted Cost of Work Performed (BCWP) and Actual Cost of Work Performed (ACWP) are calculated as the project progresses. The BCWP and ACWP data are reviewed by those monitoring project progress, and compared with the project baseline, BCWS.

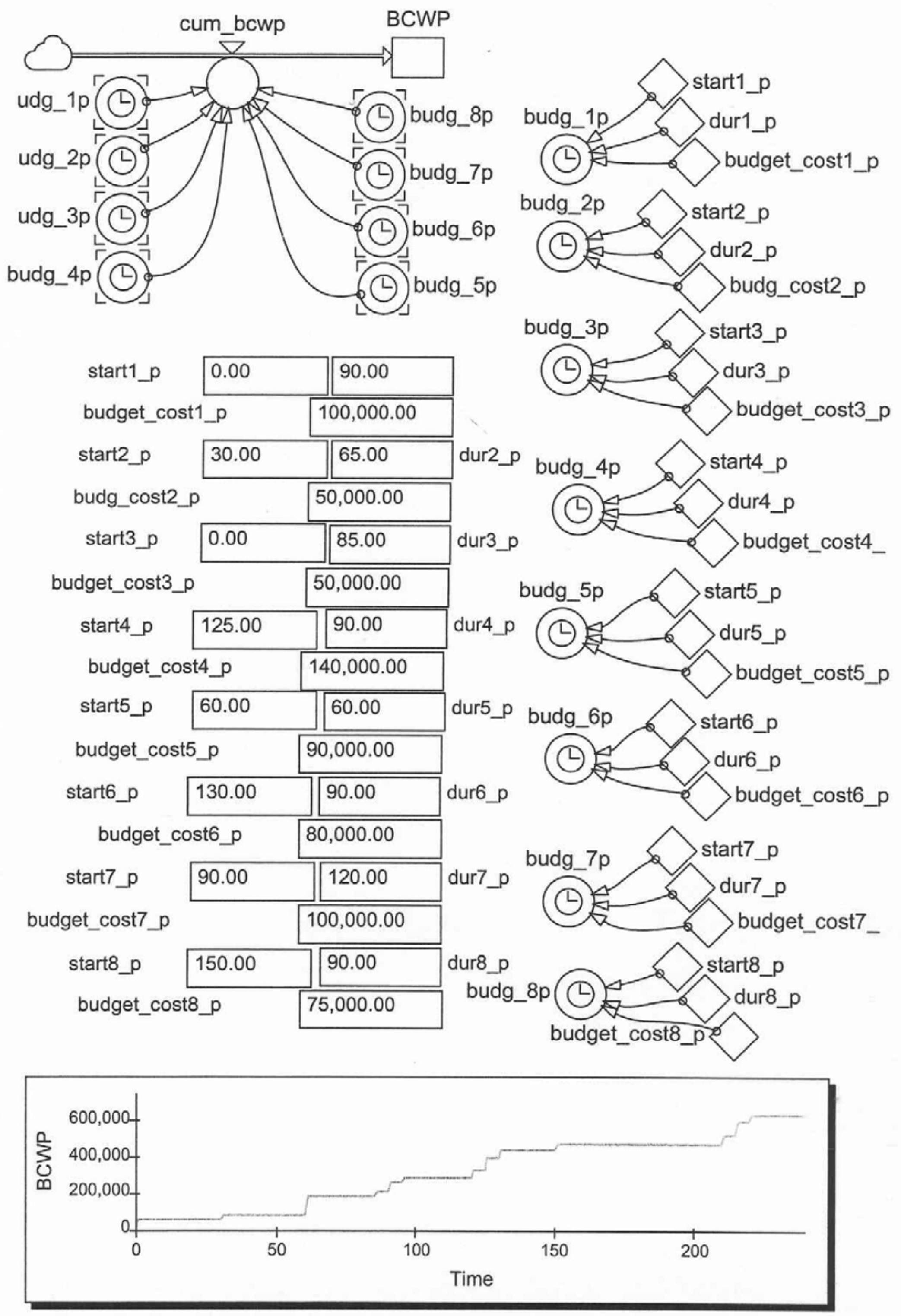
Unfortunately, delays in the collation of data and preparation of reports can occur. When data of various vintages are unwittingly collated, BCWP and ACWP reporting becomes corrupted.

This is a conceptual model which demonstrates the potential for the two key performance indicators Cost Variance (CV) and Schedule Variance (SV) to be corrupted by poor reporting practices, as occured in the P3C Upgrade Project discussed at Chapter 9.

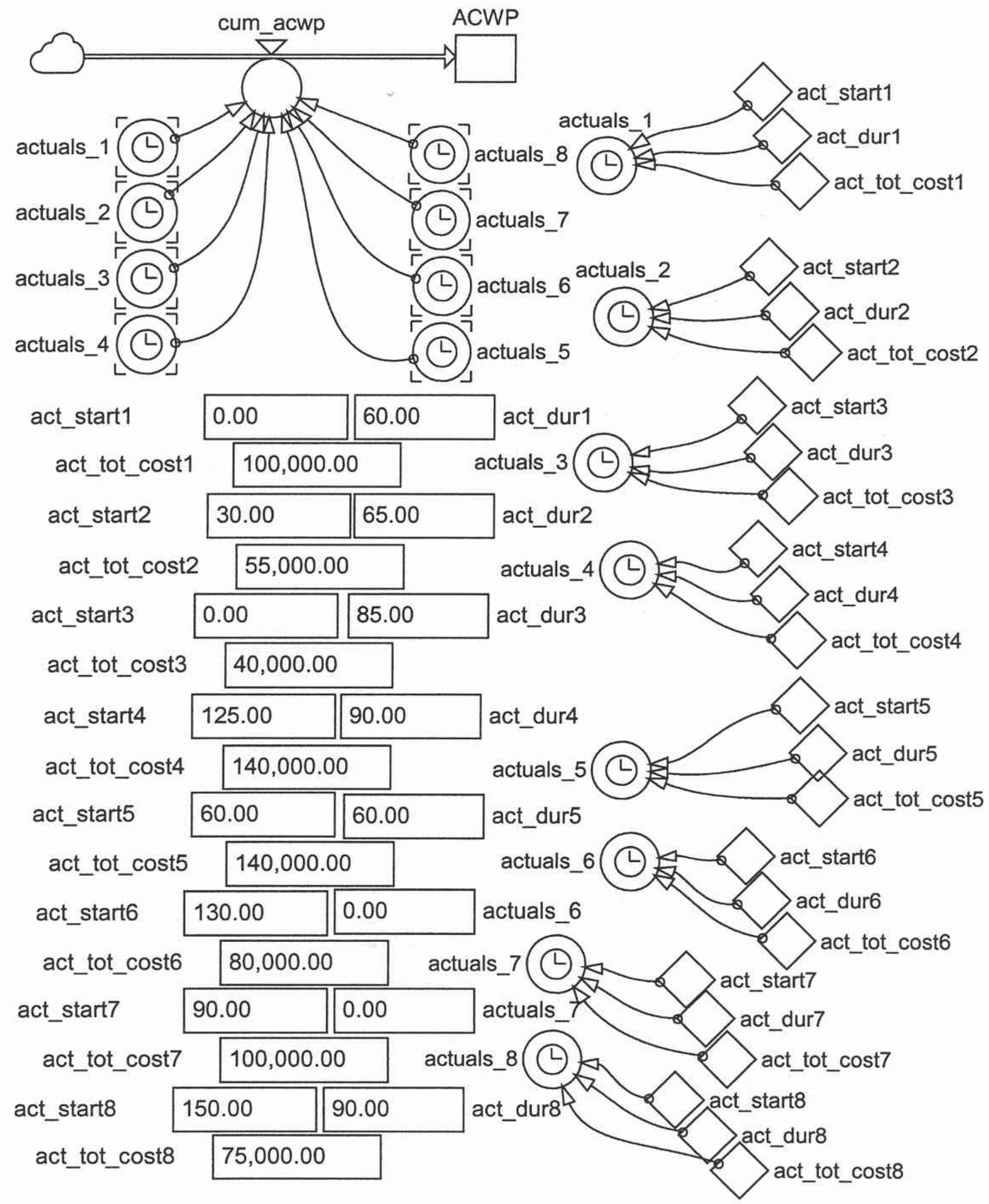
The relationship between BCWS, BCWP, ACWP, SV and CV, is depicted at Figure 9-8.

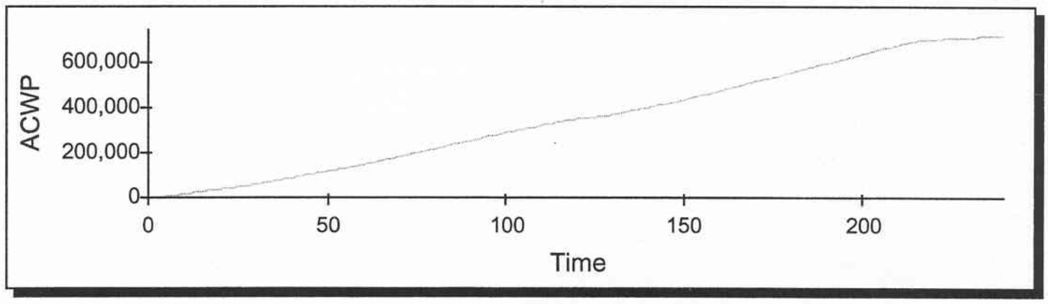


This graph shows the project baseline, Budgeted Cost of Work Scheduled (BCWS).
The time axis depicts days from project start.

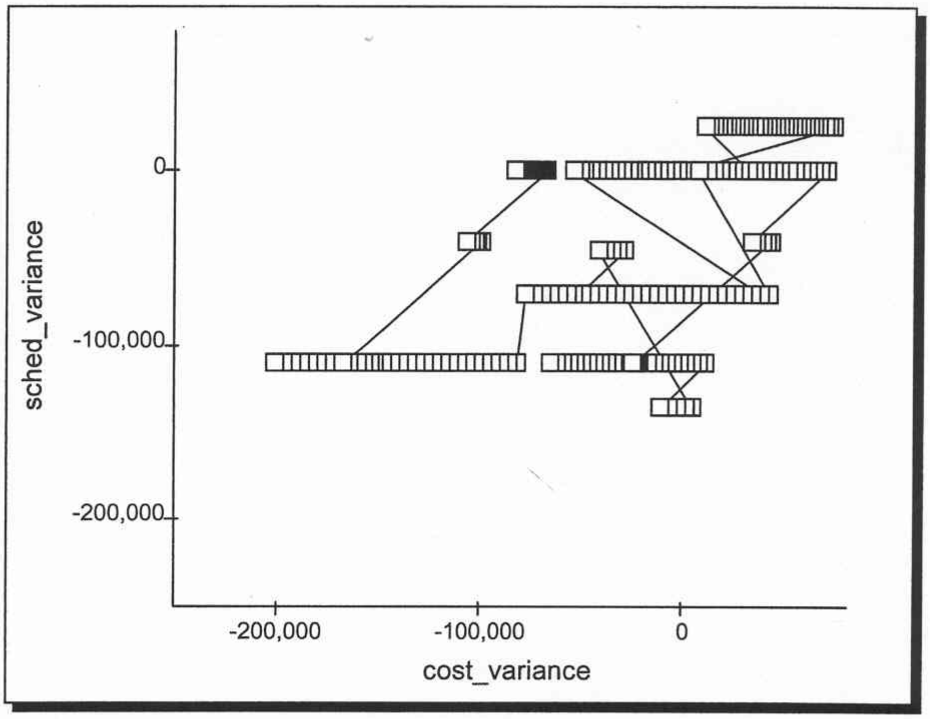


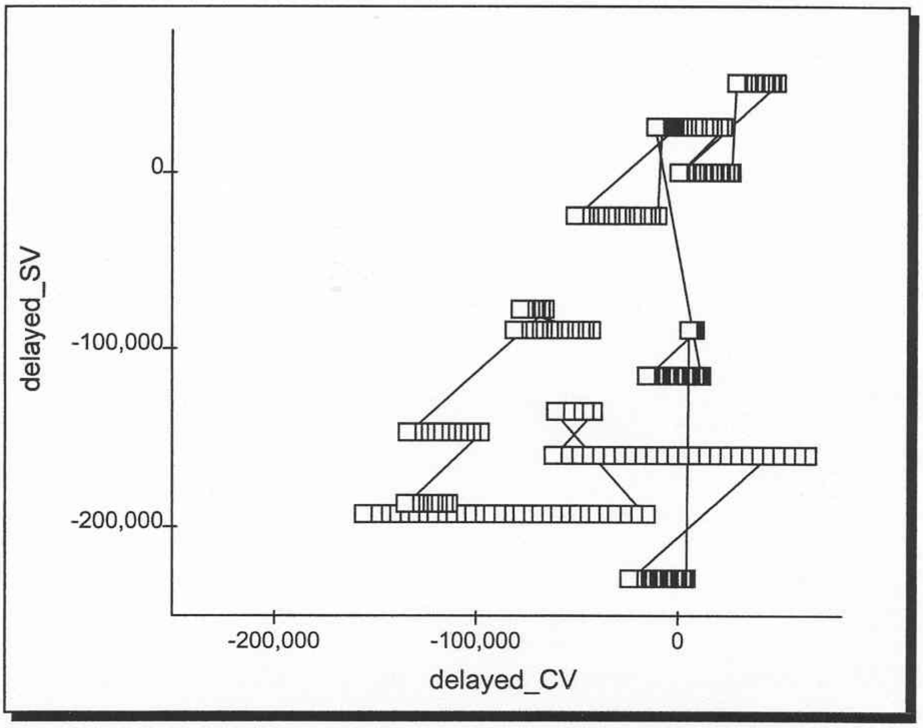
This graph shows the project baseline, Budgeted Cost of Work Performed (BCWP).
The time axis depicts days from project start.



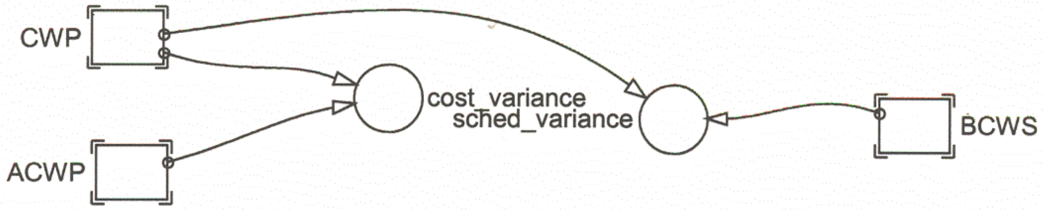


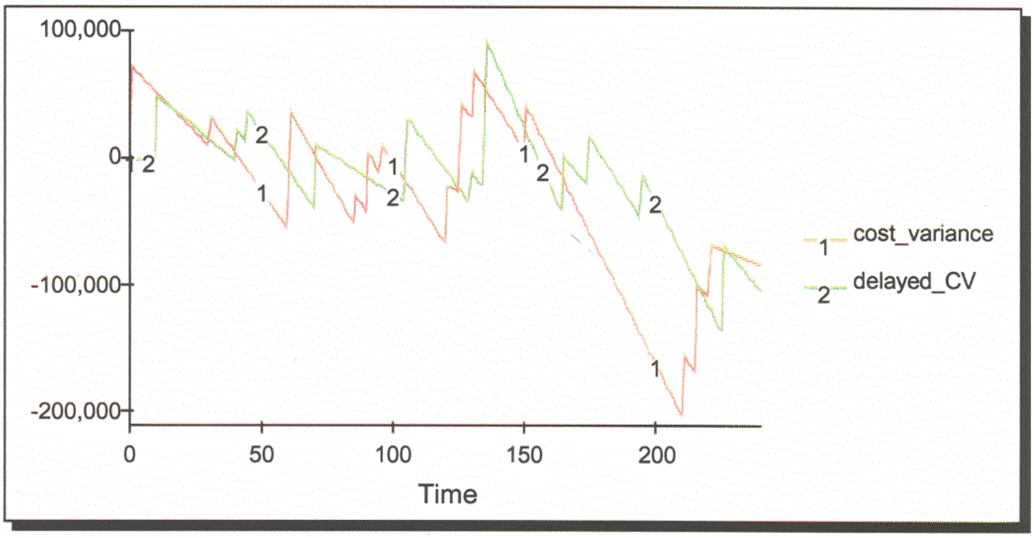
This graph shows the project baseline, Actual Cost of Work Performed (ACWP).
The time axis depicts days from project start.

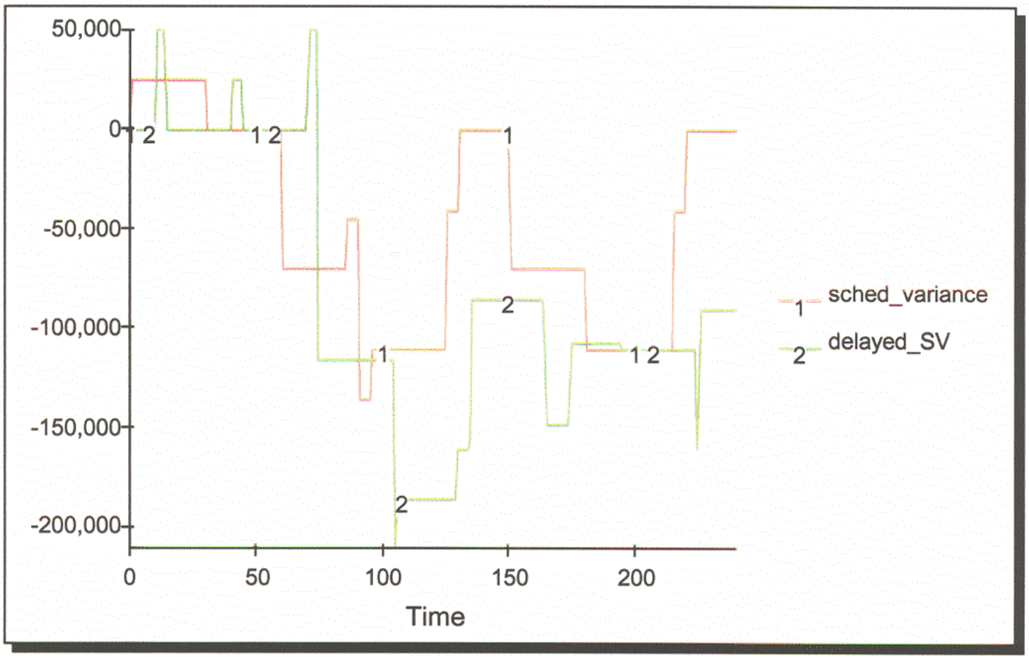




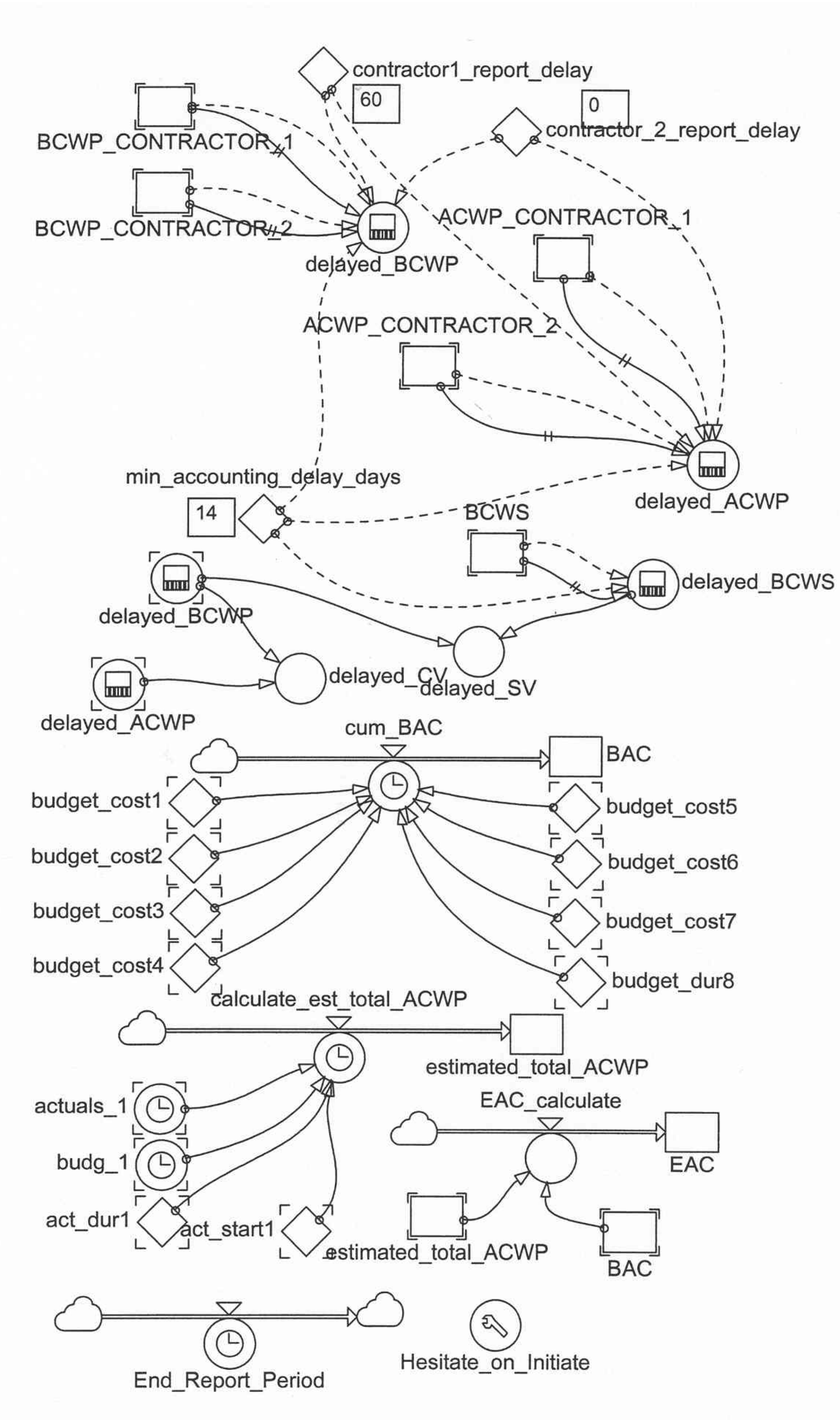
The plots in these graphs show the dynamic changes in Schedule Variance, Cost Variance, Delayed Schedule Variance and Delayed Cost Variance. These two graphs consolidate to form a bullseye diagram of the type shown at Figure 9-10. In an ideal project where reporting delays were non-existent, the dynamic plots in these two diagrams would be identical.

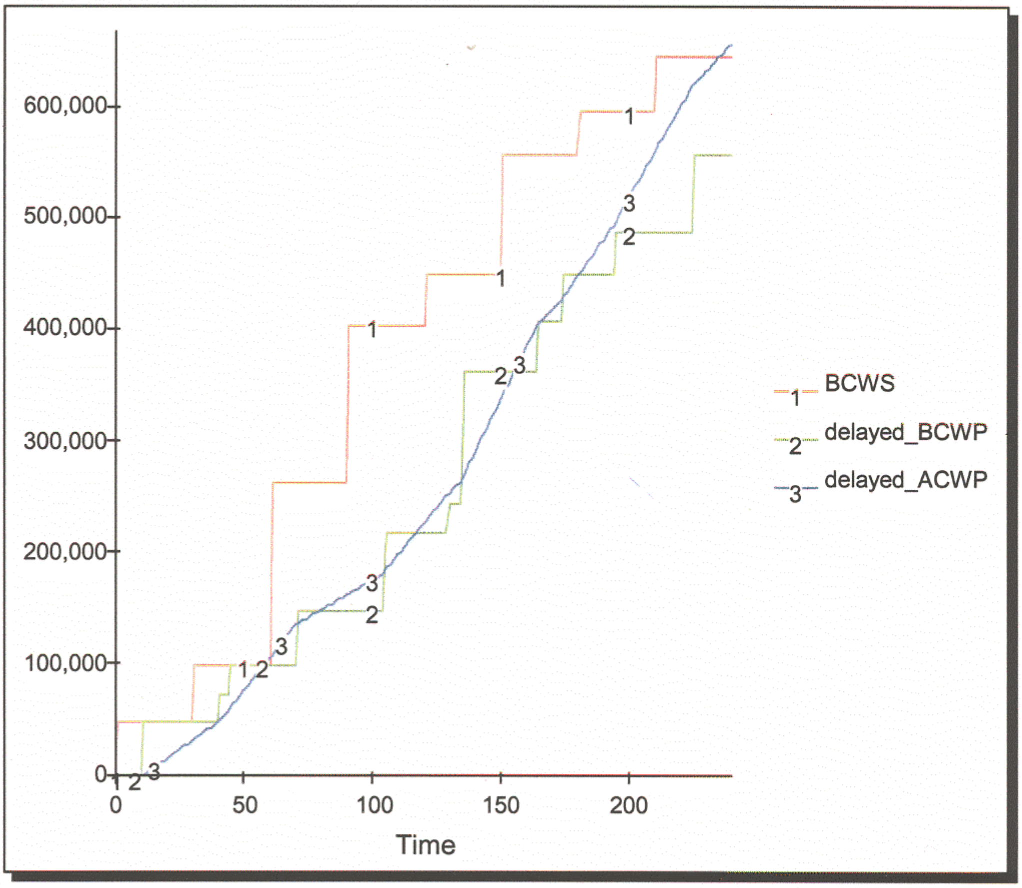


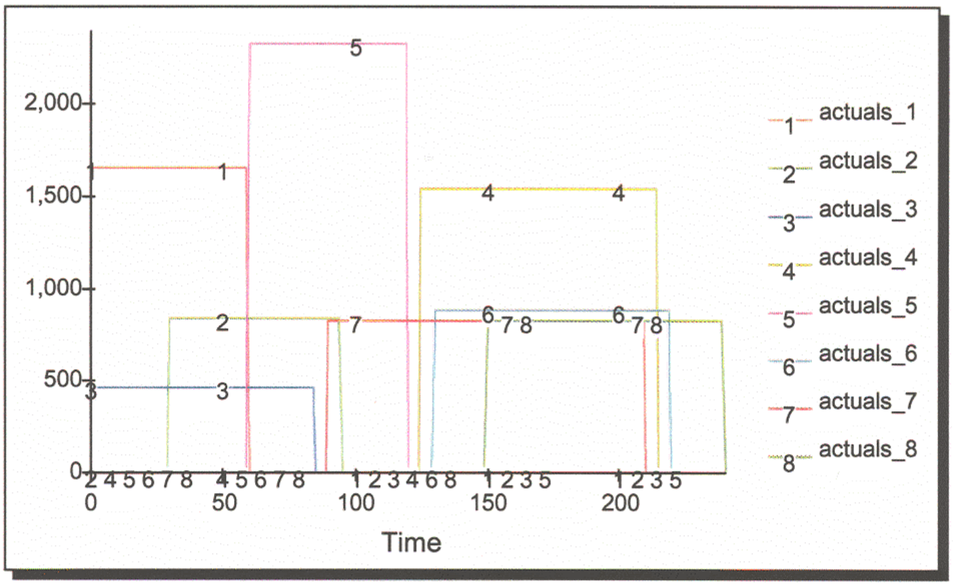




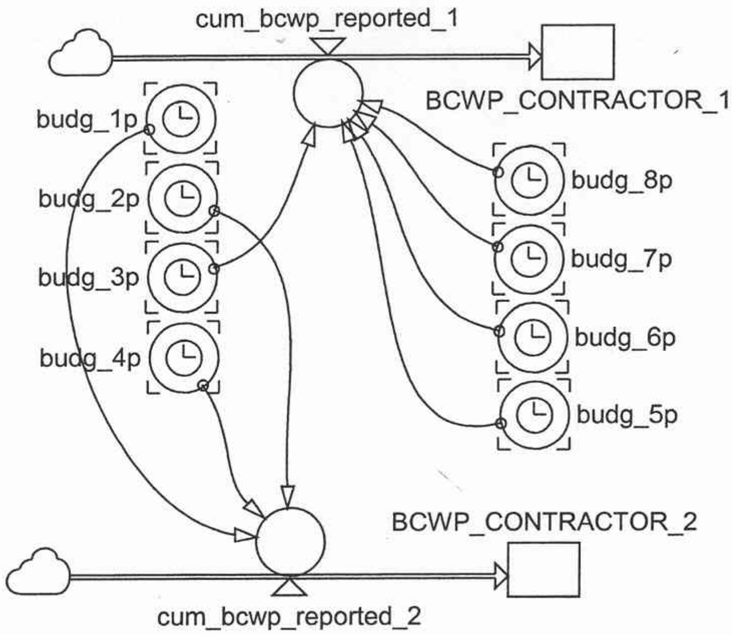
In an ideal project where reporting delays were non-existent, the two plots in each diagram would be be coincidental. Defence Acquisition Organisation has no mechanism to provide visibility of the discrepancy between the plots in each diagram. That is they have no clear way of highlighting data corruption caused by reporting delays.

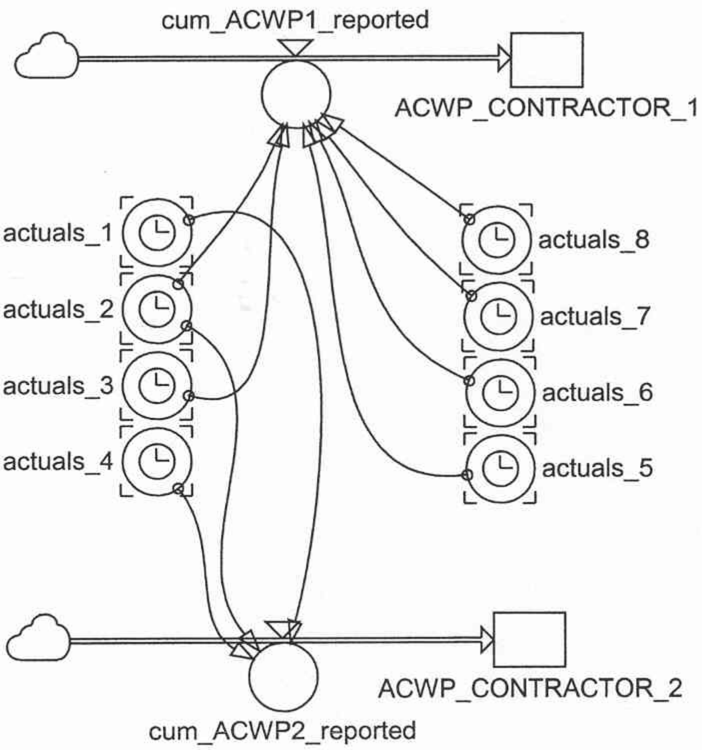

contractor1_report_delay
60
0
contractor_2_report_delay
BCWP_CONTRACTOR_1
BCWP_CONTRACTOR_2
delayed_BCWP
ACWP_CONTRACTOR_1
ACWP_CONTRACTOR_2
min_accounting_delay_days
14
delayed_ACWP
BCWS
delayed_BCWS
delayed_BCWP
delayed_ACWP
delayed_CV
delayed_SV
cum_BAC
BAC
budget_cost1
budget_cost2
budget_cost3
budget_cost4
budget_cost5
budget_cost6
budget_cost7
budget_dur8
calculate_est_total_ACWP
estimated_total_ACWP
EAC_calculate
EAC
actuals_1
budg_1
act_dur1
act_start1
estimated_total_ACWP
BAC
End_Report_Period
Hesitate_on_Initiate





This graph shows actual, rather than the planned, work being done on each of eight different project activities. Height represents rate of earned value contribution over time.


cum_bcwp_reported_1
BCWP_CONTRACTOR_1
budg_1p
budg_2p
budg_3p
budg_4p
budg_8p
budg_7p
budg_6p
budg_5p
BCWP_CONTRACTOR_2
cum_bcwp_reported_2


cum_ACWP1_reported
ACWP_CONTRACTOR_1
actuals_1
actuals_2
actuals_3
actuals_4
actuals_8
actuals_7
actuals_6
actuals_5
ACWP_CONTRACTOR_2
cum_ACWP2_reported

ACWP
INIT 0
+dt*cum_acwp
Because of the way Powersim performs its calculations, BCWP is delayed by one time period. Of course, BCWP could be calculated in advance. The one day calculation error introduced is considered insignificant.

ACWP_CONTRACTOR_1
INIT 0
+dt*cum_ACWP1_reported
Because of the way Powersim performs its calculations, BCWP is delayed by one time period. Of course, BCWP could be calculated in advance. The one day calculation error introduced is considered insignificant.

ACWP_CONTRACTOR_2
INIT 0
+dt*cum_ACWP2_reported

BAC
INIT 0
+dt*cum_BAC

BCWP
INIT 0
+dt*cum_bcwp
Because of the way Powersim performs its calculations, BCWP is delayed by one time period. Of course, BCWP could be calculated in advance. The one day calculation error introduced is considered insignificant.

BCWP_CONTRACTOR_1
INIT 0
+dt*cum_bcwp_reported_1

BCWP_CONTRACTOR_2
INIT 0
+dt*cum_bcwp_reported_2

BCWS
INIT 0
+dt*cum_bcws
Because of the way Powersim performs its calculations, BCWP is delayed by one time period. Of course, BCWP could be calculated in advance. The one day calculation error introduced is considered insignificant.

EAC
INIT 0
+dt*EAC_calculate

estimated_total_ACWP
INIT 0
+dt*calculate_est_total_ACWP
This module is designed to calculate the estimated cost to complete the project, updated by actuals.

calculate_est_total_ACWP
= IF(TIME>act_start1+act_dur1, actuals_1, budg_1)

cum_acwp
= actuals_1+actuals_2+actuals_3+actuals_4+actuals_5+actuals_6+actuals_7+actuals_8

cum_ACWP1_reported
= actuals_2+actuals_3+actuals_5+actuals_6+actuals_7+actuals_8

cum_ACWP2_reported
= actuals_1+actuals_2+actuals_4

cum_BAC
= IF(TIME=0 , budget_cost1+budget_cost2+budget_cost3+budget_cost4+budget_cost5+budget_cost6+budget_cost7+budget_dur8,0)

cum_bcwp
= budg_1p+budg_2p+budg_3p+budg_4p+budg_5p+budg_6p+budg_7p+budg_8p

cum_bcwp_reported_1
= budg_3p+budg_5p+budg_6p+budg_7p+budg_8p

cum_bcwp_reported_2
= budg_1p+budg_2p+budg_4p

cum_bcws
= budg_1+budg_2+budg_3+budg_4+budg_5+budg_6+budg_7+budg_8

EAC_calculate
= estimated_total_ACWP/1*BAC

End_Report_Period
= IF(((TIME) MOD 30), 1, 0)*100

actuals_1
= PULSEIF(TIME>=act_start1 , act_tot_cost1/act_dur1)*IF(TIME>=(act_start1+act_dur1) ,0 ,1)

actuals_2
= PULSEIF(TIME>=act_start2 , act_tot_cost2/act_dur2)*IF(TIME>=(act_start2+act_dur2) , 0,1)

actuals_3
= PULSEIF(TIME>=act_start3 , act_tot_cost3/act_dur3)*IF(TIME>=(act_start3+act_dur3) , 0, 1)

actuals_4
= PULSEIF(TIME>=act_start4 , act_tot_cost4/act_dur4)*IF(TIME>=(act_start4+act_dur4) ,0,1)

actuals_5
= PULSEIF(TIME>=act_start5 , act_tot_cost5/act_dur5)*IF(TIME>=(act_start5+act_dur5) , 0, 1)

actuals_6
= PULSEIF(TIME>=act_start6 , act_tot_cost6/act_dur6)*IF(TIME>=(act_start6+act_dur6) , 0, 1)

actuals_7
= PULSEIF(TIME>=act_start7 , act_tot_cost7/act_dur7)*IF(TIME>=(act_start7+act_dur7) , 0, 1)

actuals_8
= PULSEIF(TIME>=act_start8 , act_tot_cost8/act_dur8)*IF(TIME>=(act_start8+act_dur8) , 0, 1)

budg_1
= PULSEIF(TIME=sched_start1 , budget_cost1/2)+PULSEIF(TIME=(sched_start1+ budget_dur1) , budget_cost1/2)

budg_1p
= PULSEIF(TIME=start1_p , budget_cost1_p/2)+PULSEIF(TIME=(start1_p+dur1_p) , budget_cost1_p/2)

budg_2
= PULSEIF(TIME=sched_start2 , budget_cost2/2)+PULSEIF(TIME=(sched_start2+ budget_dur2) , budget_cost2/2)

budg_2p
= PULSEIF(TIME=start2_p , budg_cost2_p/2)+PULSEIF(TIME=(start2_p+dur2_p) , budg_cost2_p/2)

budg_3
= PULSEIF(TIME=sched_start3 , budget_cost3/2)+PULSEIF(TIME=(sched_start3+ budget_dur3) , budget_cost3/2)

budg_3p
= PULSEIF(TIME=start3_p , budget_cost3_p/2)+PULSEIF(TIME=(start3_p+dur3_p) , budget_cost3_p/2)

budg_4
= PULSEIF(TIME=sched_start4 , budget_cost4/2)+PULSEIF(TIME=(sched_start4+ budget_dur4) , budget_cost4/2)

budg_4p
= PULSEIF(TIME=start4_p , budget_cost4_p/2)+PULSEIF(TIME=(start4_p+dur4_p) , budget_cost4_p/2)

budg_5
= PULSEIF(TIME=sched_start5 , budget_cost5/2)+PULSEIF(TIME=(sched_start5+ budget_dur5) , budget_cost5/2)

budg_5p
= PULSEIF(TIME=start5_p , budget_cost5_p/2)+PULSEIF(TIME=(start5_p+dur5_p) , budget_cost5_p/2)

○ budg_6
= PULSEIF(TIME=sched_start6 , budget_cost6/2)+PULSEIF(TIME=(sched_start6+ budget_dur6) , budget_cost6/2)

○ budg_6p
= PULSEIF(TIME=start6_p , budget_cost6_p/2)+PULSEIF(TIME=(start6_p+dur6_p) , budget_cost6_p/2)

○ budg_7
= PULSEIF(TIME=sched_start7 , budget_cost7/2)+PULSEIF(TIME=(sched_start7+ budget_dur7) , budget_cost7/2)

○ budg_7p
= PULSEIF(TIME=start7_p , budget_cost7_p/2)+PULSEIF(TIME=(start7_p+dur7_p) , budget_cost7_p/2)

○ budg_8
= PULSEIF(TIME=sched_start8 , budget_cost8/2)+PULSEIF(TIME=(sched_start8+ budget_dur8) , budget_cost8/2)

○ budg_8p
= PULSEIF(TIME=start8_p , budget_cost8_p/2)+PULSEIF(TIME=(start8_p+dur8_p) , budget_cost8_p/2)

○ cost_variance
= BCWP-ACWP

○ delayed_ACWP
= DELAYPPL(ACWP_CONTRACTOR_1, (contractor1_report_delay+ min_accounting_delay_days))+DELAYPPL(ACWP_CONTRACTOR_2, (contractor_2_report_delay+contractor_2_report_delay))

○ delayed_BCWP
= DELAYPPL(BCWP_CONTRACTOR_1, (contractor1_report_delay+ min_accounting_delay_days))+DELAYPPL(BCWP_CONTRACTOR_2, (contractor_2_report_delay+contractor_2_report_delay))

○ delayed_BCWS
= DELAYPPL(BCWS, min_accounting_delay_days)

○ delayed_CV
= delayed_BCWP-delayed_ACWP

○ delayed_SV
= delayed_BCWP-delayed_BCWS

Note that in reality BCWS is not delayed. It is the baseline schedule agreed at the time of contract signature and, is embodied in the contract. This information is available at 'day zero' of the contract and calculated at that point.

○ Hesitate_on_Initiate
= PAUSEIF(TIME=1)

○ sched_variance
= BCWP-BCWS

◇ act_dur1
= 60

◇ act_dur2
= 65

Task tool 65 days instead of 60.

◇ act_dur3
= 85

Task was scheduled to take 60 days but took 85.

◇ act_dur4
= 90

◇ act_dur5
= 60

◇ act_dur6
= 90

◇ act_dur7
= 120

Work appears to be on schedule for completion

◇ act_dur8
= 90

- act_start1
  - = 0
  - For the purpose of this simulation, 30 days approximately equals one month.
- act_start2
  - = 30
- act_start3
  - = 0
  - Task started 30 days early.
- act_start4
  - = 125
  - Task was due to start at day 60 but did not start until day 125.
- act_start5
  - = 60
- act_start6
  - = 130
  - Task was due to start at day 90 but runs 40 days late.
- act_start7
  - = 90
  - Work began on time.
- act_start8
  - = 150
- act_tot_cost1
  - = 100000
- act_tot_cost2
  - = 55000
  - Budgeted cost of task was $50,000. Cost overrun was $5,000. Actual total cost $55,000
- act_tot_cost3
  - = 40000
  - Budgeted cost was $50,000. Costs were unerrun by $10,000, probalbly because of early start. Total actual cost $40,000
- act_tot_cost4
  - = 140000
- act_tot_cost5
  - = 140000
  - Budgeted cost $90,000. Cost overrun $50,000. Total expected cost is $140,000.
- act_tot_cost6
  - = 80000
- act_tot_cost7
  - = 100000
- act_tot_cost8
  - = 75000
- budg_cost2_p
  - = 50000
- budget_cost1
  - = 100000
- budget_cost1_p
  - = 100000
- budget_cost2
  - = 50000
- budget_cost3
  - = 50000
- budget_cost3_p
  - = 50000
- budget_cost4
  - = 140000
- budget_cost4_p
  - = 140000
- budget_cost5
  - = 90000

◇ budget_cost5_p
= 90000
◇ budget_cost6
= 80000
◇ budget_cost6_p
= 80000
◇ budget_cost7
= 100000
◇ budget_cost7_p
= 100000
◇ budget_cost8
= 75000
◇ budget_cost8_p
= 75000
◇ budget_dur1
= 60
◇ budget_dur2
= 60
◇ budget_dur3
= 60
◇ budget_dur4
= 90
◇ budget_dur5
= 60
◇ budget_dur6
= 90
◇ budget_dur7
= 120
◇ budget_dur8
= 90
◇ contractor_2_report_delay
= 0
◇ contractor1_report_delay
= 60
◇ dur1_p
= 60
◇ dur2_p
= 65
Task tool 65 days instead of 60.
◇ dur3_p
= 85
Task was scheduled to take 60 days but took 85.
◇ dur4_p
= 90
◇ dur5_p
= 60
◇ dur6_p
= 90
◇ dur7_p
= 120
Work appears to be on schedule for completion
◇ dur8_p
= 90
◇ min_accounting_delay_days
= 14
◇ sched_start1
= 0
For the purpose of this simulation, 30 days approximately equals one month.

◇ sched_start2
= 30
◇ sched_start3
= 30
◇ sched_start4
= 60
◇ sched_start5
= 60
◇ sched_start6
= 90
◇ sched_start7
= 90
◇ sched_start8
= 150
◇ start1_p
= 0
For the purpose of this simulation, 30 days approximately equals one month.
◇ start2_p
= 30
◇ start3_p
= 0
Task started 30 days early.
◇ start4_p
= 125
Task was due to start at day 60 but did not start until day 125.
◇ start5_p
= 60
◇ start6_p
= 130
Task was due to start at day 90 but runs 40 days late.
◇ start7_p
= 90
Work began on time.
◇ start8_p
= 150

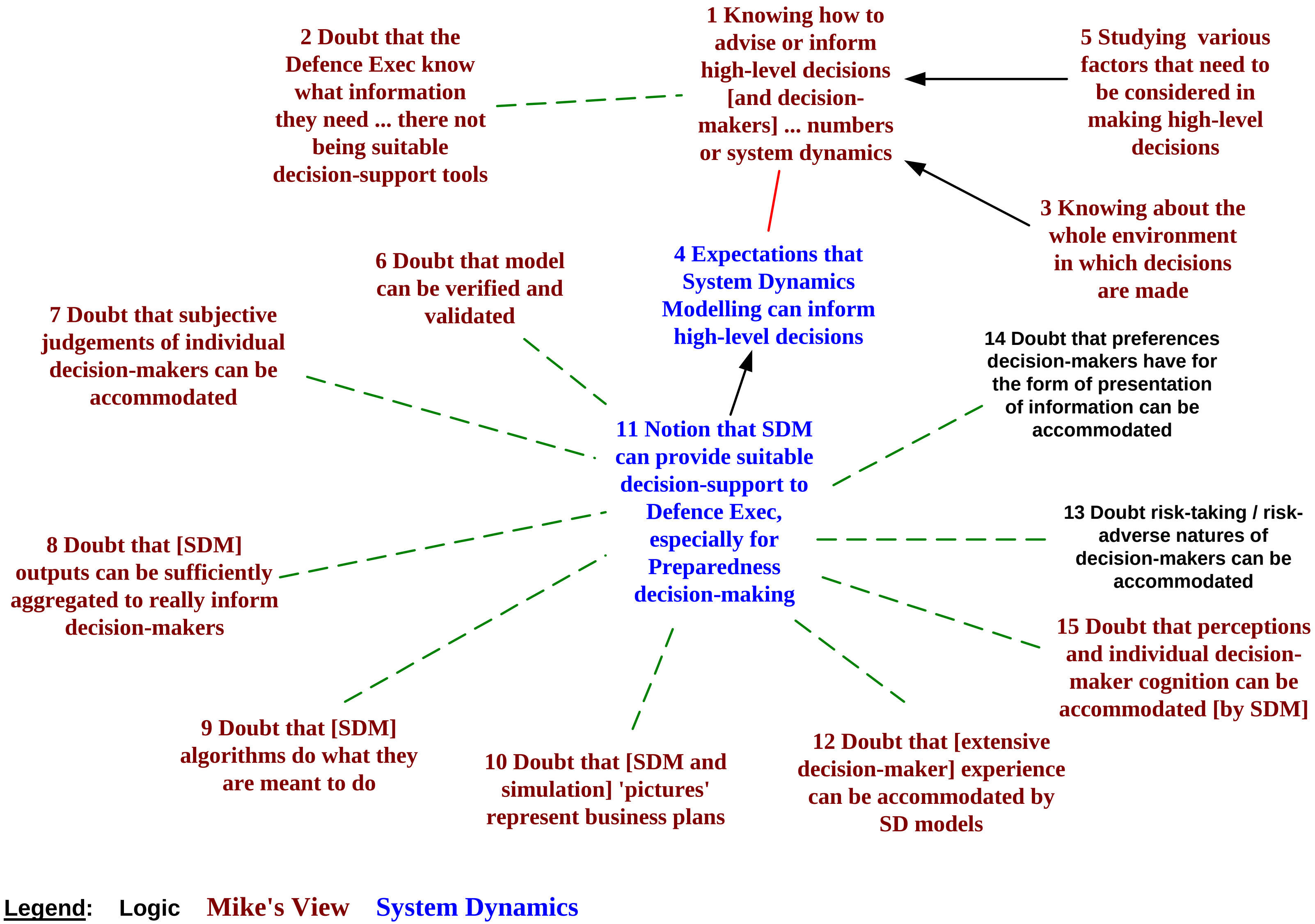
ANNEX D: SYSTEMS THINKING AND SYSTEM DYNAMICS MODELLING – AIDS TO DECISION MAKING – A CASE STUDY IN RELIABILITY PREDICTION

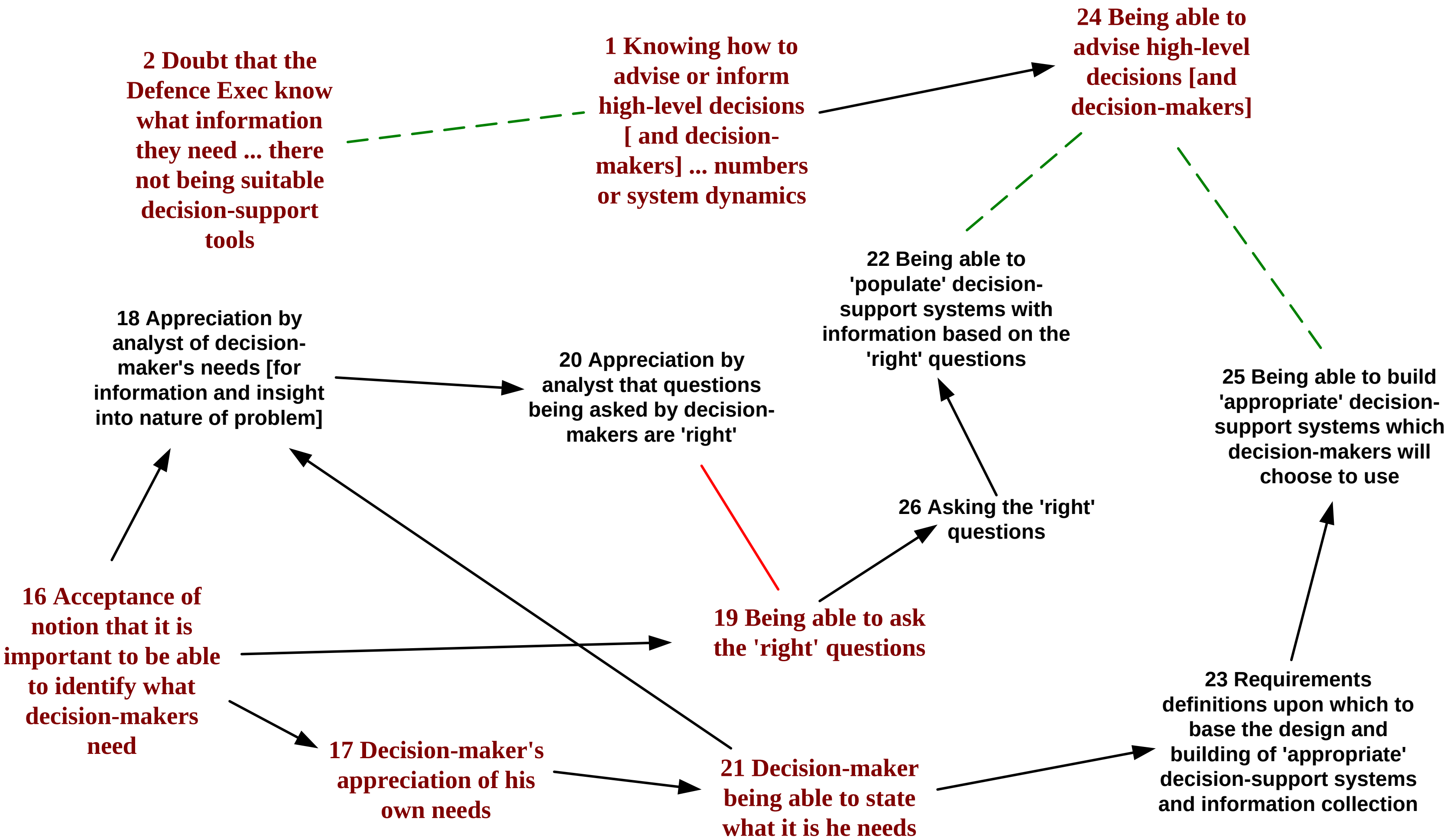
Pages 434 – 439 of the original thesis contain a reprint of the following journal article:

McLucas, A.C. 1999. 'Systems thinking and system dynamics modelling – aids to decision making: A case study in reliability prediction.' In: *Journal of Battlefield Technology,* Vol. 2, No. 2, July 1999.

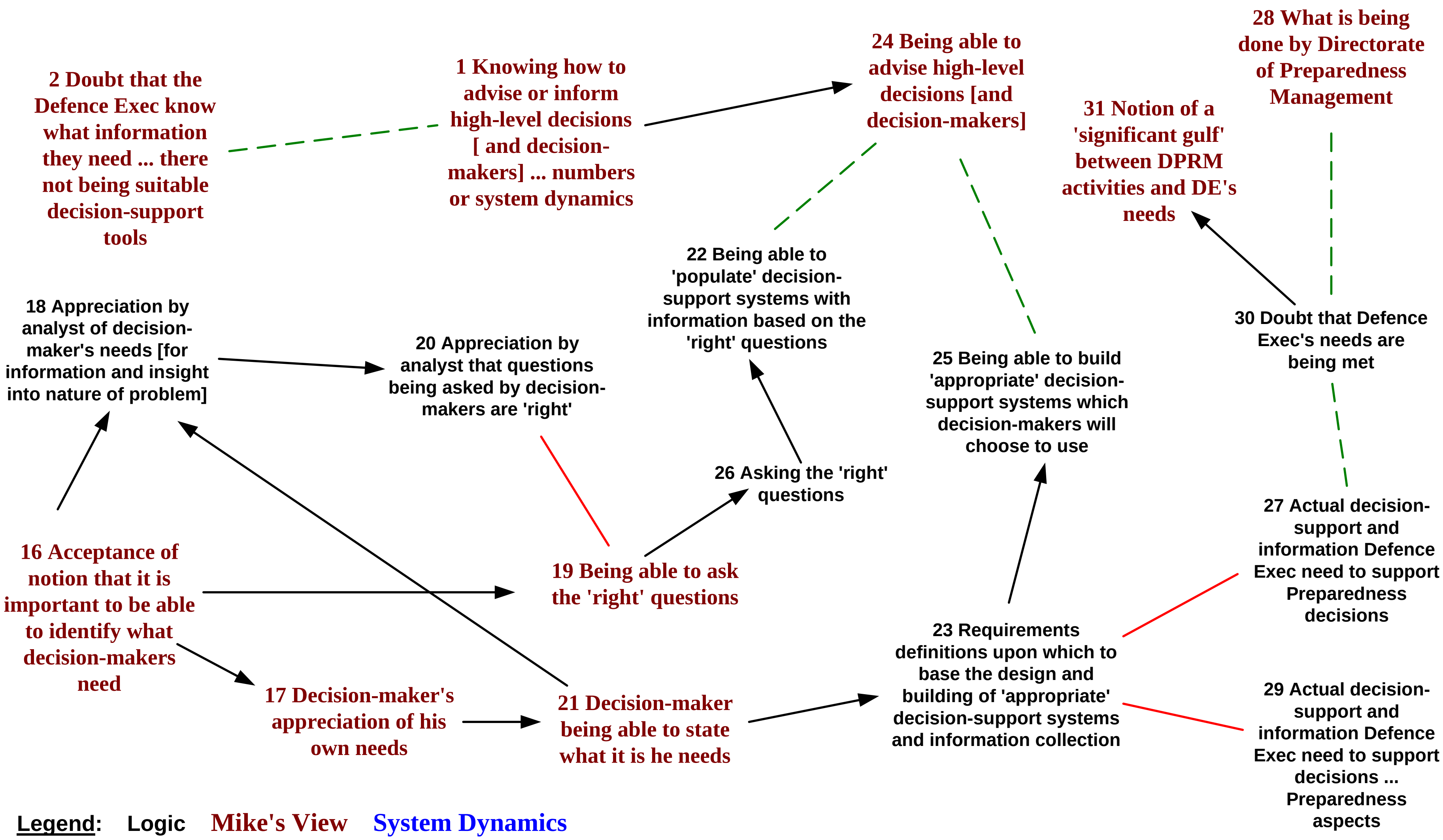
The Journal of Battlefield Technology can be found at *www.argospress.com*

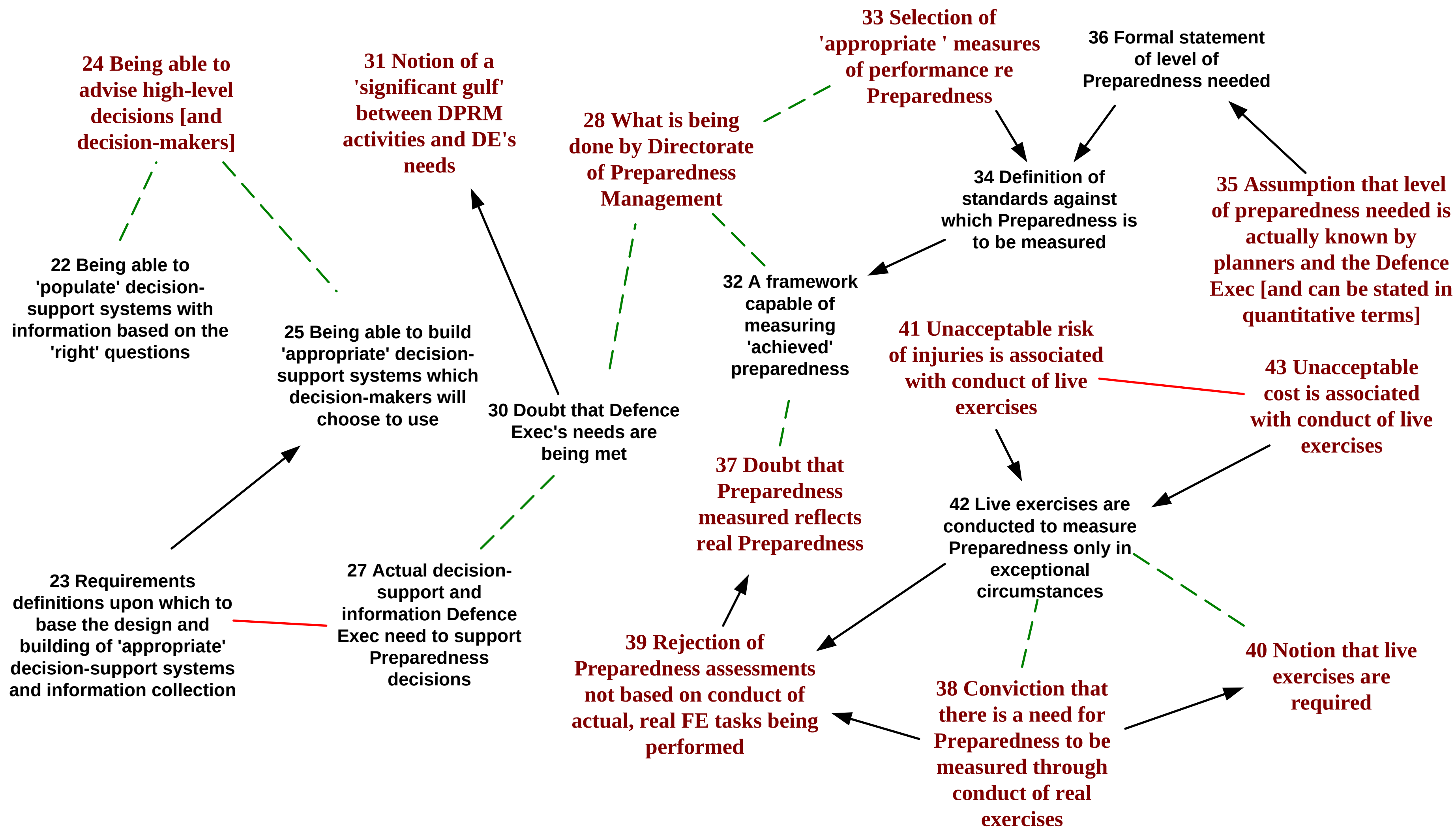
ANNEX E: DEFENCE PREPAREDNESS RESOURCE MODELLING – COGNITIVE MAP


1 Knowing how to advise or inform high-level decisions [and decision-makers] ... numbers or system dynamics
2 Doubt that the Defence Exec know what information they need ... there not being suitable decision-support tools
5 Studying various factors that need to be considered in making high-level decisions
3 Knowing about the whole environment in which decisions are made
4 Expectations that System Dynamics Modelling can inform high-level decisions
6 Doubt that model can be verified and validated
7 Doubt that subjective judgements of individual decision-makers can be accommodated
14 Doubt that preferences decision-makers have for the form of presentation of information can be accommodated
11 Notion that SDM can provide suitable decision-support to Defence Exec, especially for Preparedness decision-making
8 Doubt that [SDM] outputs can be sufficiently aggregated to really inform decision-makers
13 Doubt risk-taking / risk-adverse natures of decision-makers can be accommodated
15 Doubt that perceptions and individual decision-maker cognition can be accommodated [by SDM]
9 Doubt that [SDM] algorithms do what they are meant to do
10 Doubt that [SDM and simulation] 'pictures' represent business plans
12 Doubt that [extensive decision-maker] experience can be accommodated by SD models
Legend: Logic Mike's View System Dynamics

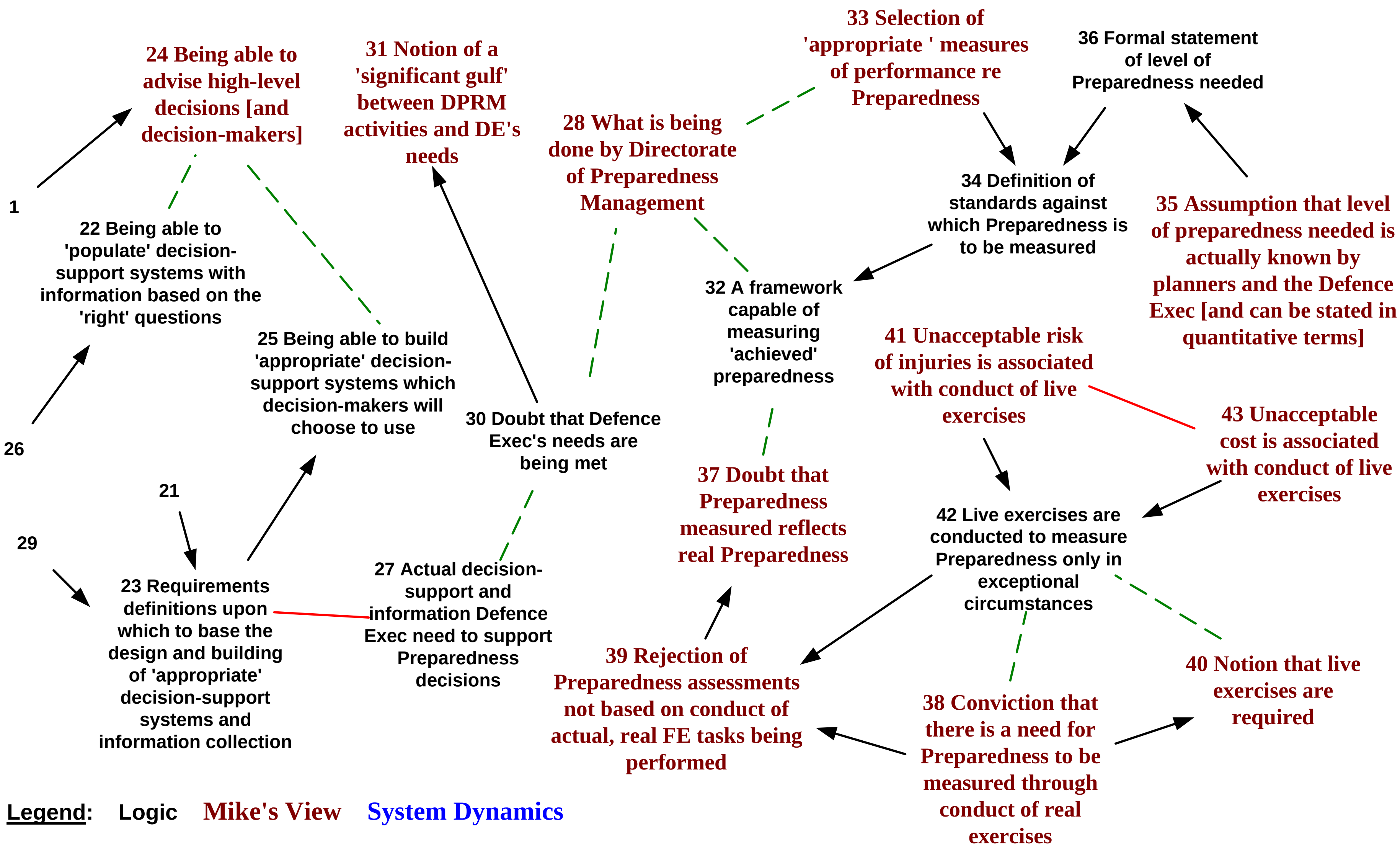


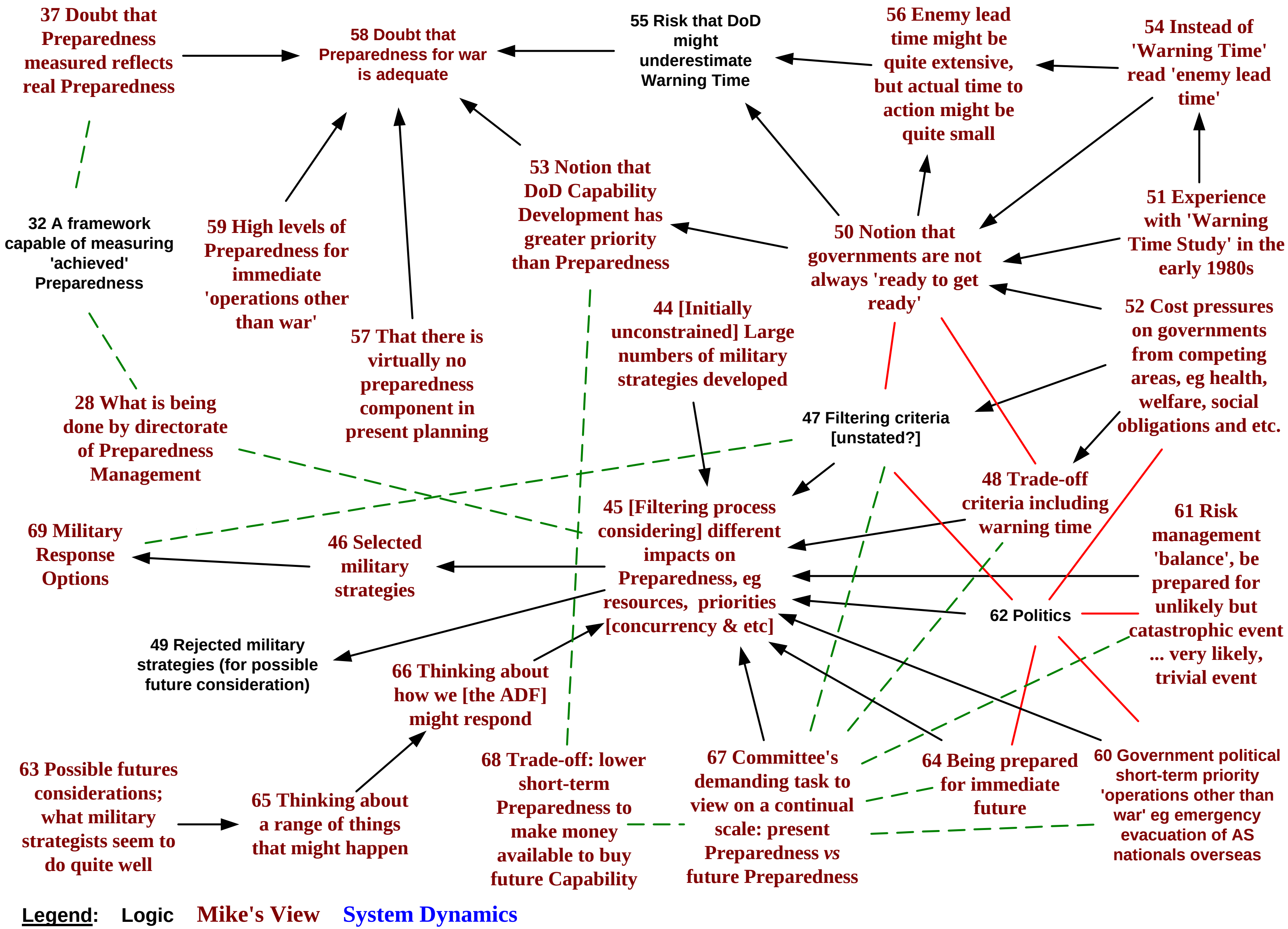
Legend: Logic Mike's View System Dynamics

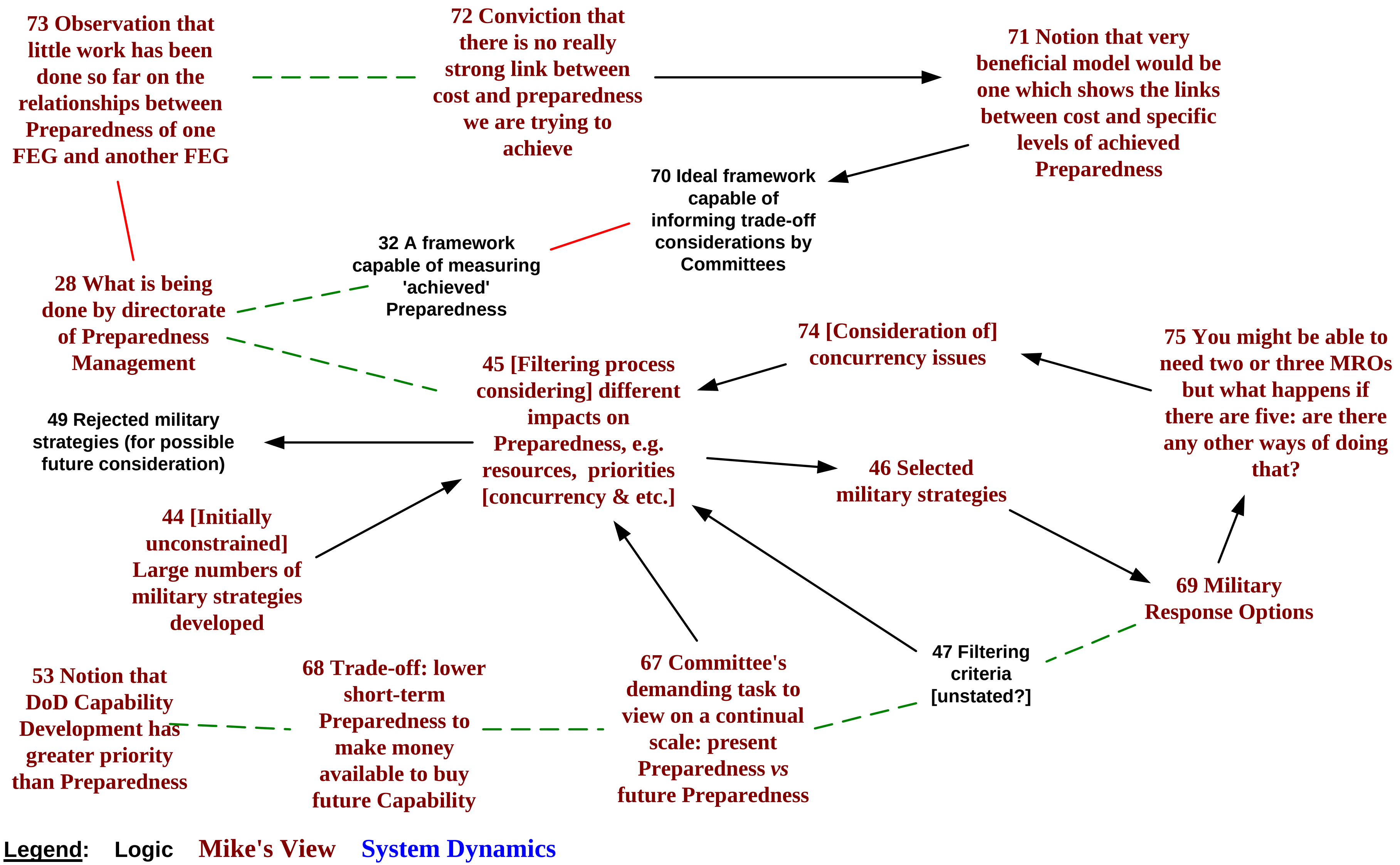

2 Doubt that the Defence Exec know what information they need ... there not being suitable decision-support tools
1 Knowing how to advise or inform high-level decisions [and decision-makers] ... numbers or system dynamics
24 Being able to advise high-level decisions [and decision-makers]
28 What is being done by Directorate of Preparedness Management
31 Notion of a 'significant gulf' between DPRM activities and DE's needs
22 Being able to 'populate' decision-support systems with information based on the 'right' questions
18 Appreciation by analyst of decision-maker's needs [for information and insight into nature of problem]
20 Appreciation by analyst that questions being asked by decision-makers are 'right'
30 Doubt that Defence Exec's needs are being met
25 Being able to build 'appropriate' decision-support systems which decision-makers will choose to use
26 Asking the 'right' questions
27 Actual decision-support and information Defence Exec need to support Preparedness decisions
16 Acceptance of notion that it is important to be able to identify what decision-makers need
19 Being able to ask the 'right' questions
23 Requirements definitions upon which to base the design and building of 'appropriate' decision-support systems and information collection
17 Decision-maker's appreciation of his own needs
21 Decision-maker being able to state what it is he needs
29 Actual decision-support and information Defence Exec need to support decisions ... Preparedness aspects
Legend: Logic Mike's View System Dynamics

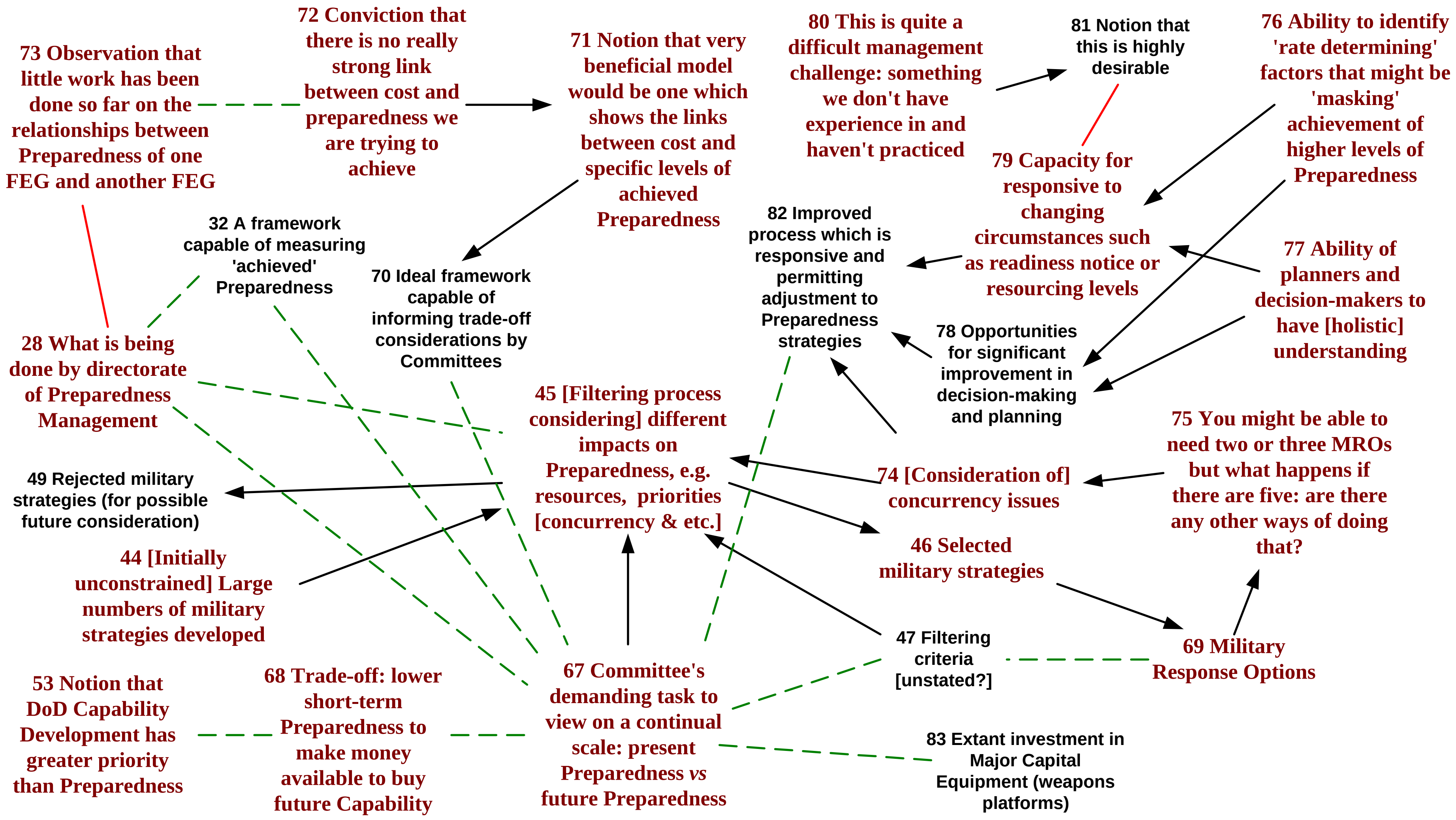


Legend: Logic Mike's View System Dynamics

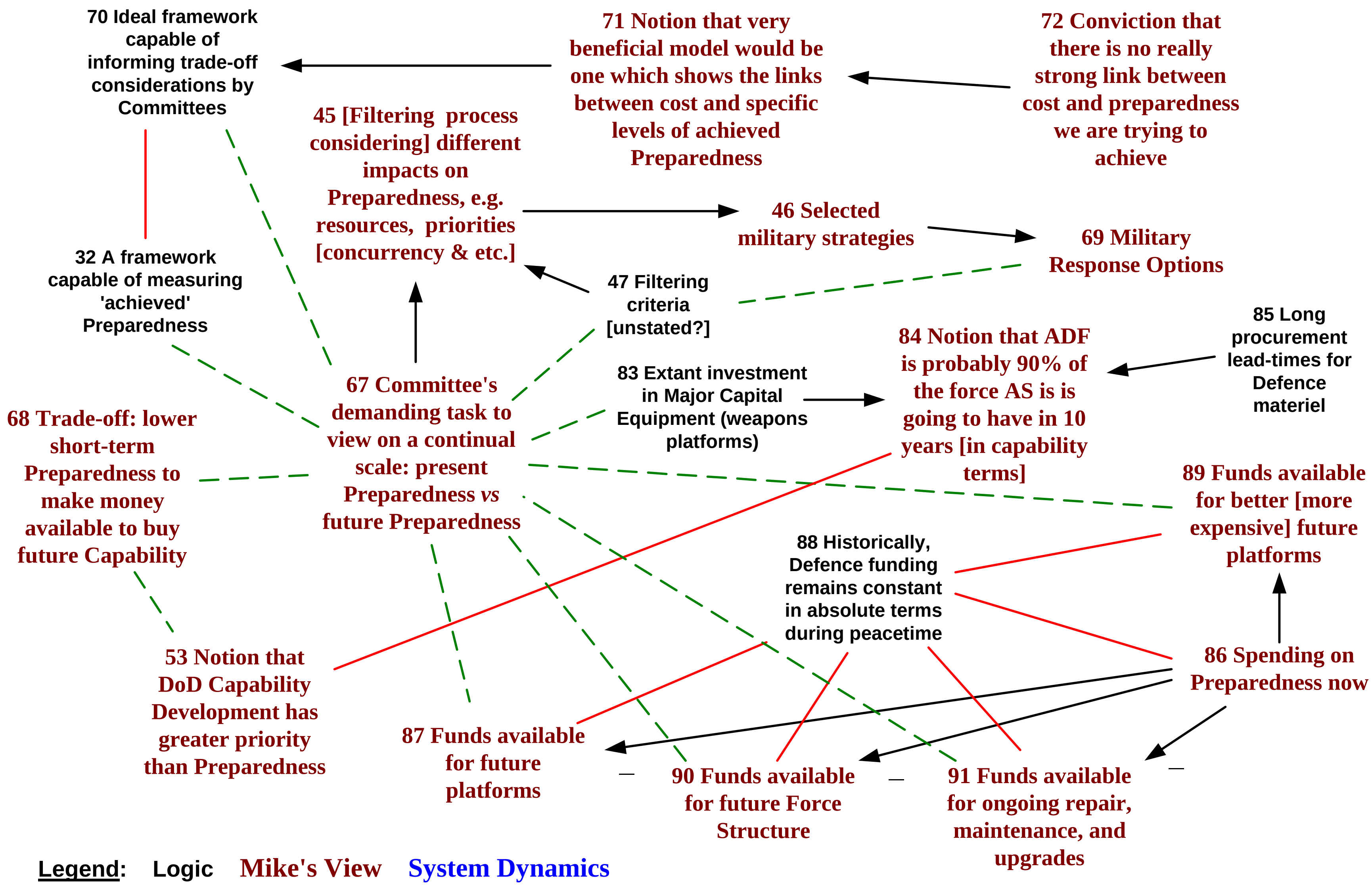

24 Being able to advise high-level decisions [and decision-makers]
31 Notion of a 'significant gulf' between DPRM activities and DE's needs
33 Selection of 'appropriate ' measures of performance re Preparedness
36 Formal statement of level of Preparedness needed
28 What is being done by Directorate of Preparedness Management
34 Definition of standards against which Preparedness is to be measured
35 Assumption that level of preparedness needed is actually known by planners and the Defence Exec [and can be stated in quantitative terms]
1
22 Being able to 'populate' decision-support systems with information based on the 'right' questions
32 A framework capable of measuring 'achieved' preparedness
25 Being able to build 'appropriate' decision-support systems which decision-makers will choose to use
41 Unacceptable risk of injuries is associated with conduct of live exercises
30 Doubt that Defence Exec's needs are being met
43 Unacceptable cost is associated with conduct of live exercises
26
37 Doubt that Preparedness measured reflects real Preparedness
21
42 Live exercises are conducted to measure Preparedness only in exceptional circumstances
29
27 Actual decision-support and information Defence Exec need to support Preparedness decisions
23 Requirements definitions upon which to base the design and building of 'appropriate' decision-support systems and information collection
39 Rejection of Preparedness assessments not based on conduct of actual, real FE tasks being performed
40 Notion that live exercises are required
38 Conviction that there is a need for Preparedness to be measured through conduct of real exercises
Legend: Logic Mike's View System Dynamics

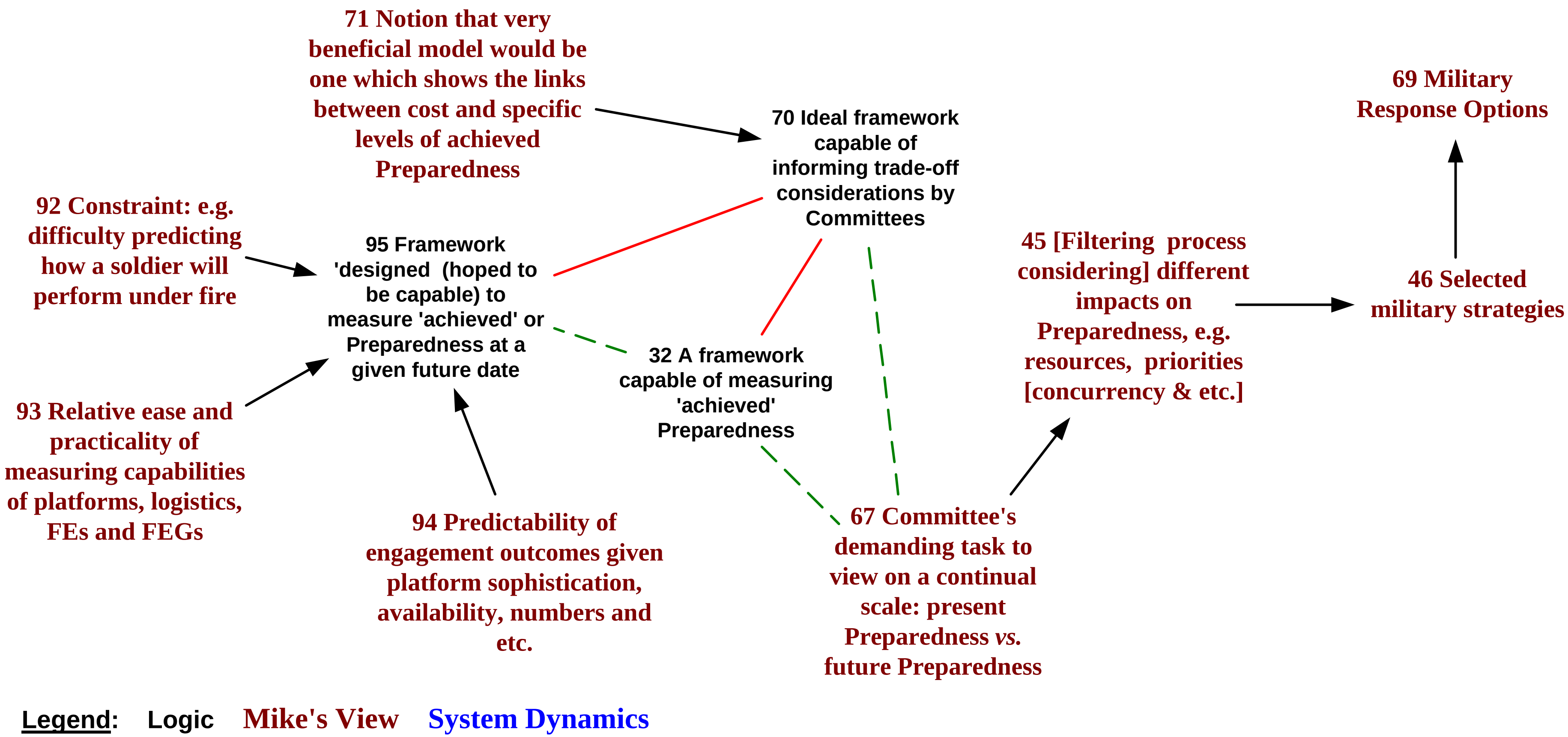

37 Doubt that Preparedness measured reflects real Preparedness
58 Doubt that Preparedness for war is adequate
55 Risk that DoD might underestimate Warning Time
56 Enemy lead time might be quite extensive, but actual time to action might be quite small
54 Instead of 'Warning Time' read 'enemy lead time'
32 A framework capable of measuring 'achieved' Preparedness
59 High levels of Preparedness for immediate 'operations other than war'
53 Notion that DoD Capability Development has greater priority than Preparedness
50 Notion that governments are not always 'ready to get ready'
51 Experience with 'Warning Time Study' in the early 1980s
57 That there is virtually no preparedness component in present planning
44 [Initially unconstrained] Large numbers of military strategies developed
52 Cost pressures on governments from competing areas, eg health, welfare, social obligations and etc.
28 What is being done by directorate of Preparedness Management
47 Filtering criteria [unstated?]
48 Trade-off criteria including warning time
45 [Filtering process considering] different impacts on Preparedness, eg resources, priorities [concurrency & etc]
61 Risk management 'balance', be prepared for unlikely but catastrophic event ... very likely, trivial event
69 Military Response Options
46 Selected military strategies
62 Politics
49 Rejected military strategies (for possible future consideration)
66 Thinking about how we [the ADF] might respond
63 Possible futures considerations; what military strategists seem to do quite well
65 Thinking about a range of things that might happen
68 Trade-off: lower short-term Preparedness to make money available to buy future Capability
67 Committee's demanding task to view on a continual scale: present Preparedness vs future Preparedness
64 Being prepared for immediate future
60 Government political short-term priority 'operations other than war' eg emergency evacuation of AS nationals overseas
Legend: Logic Mike's View System Dynamics

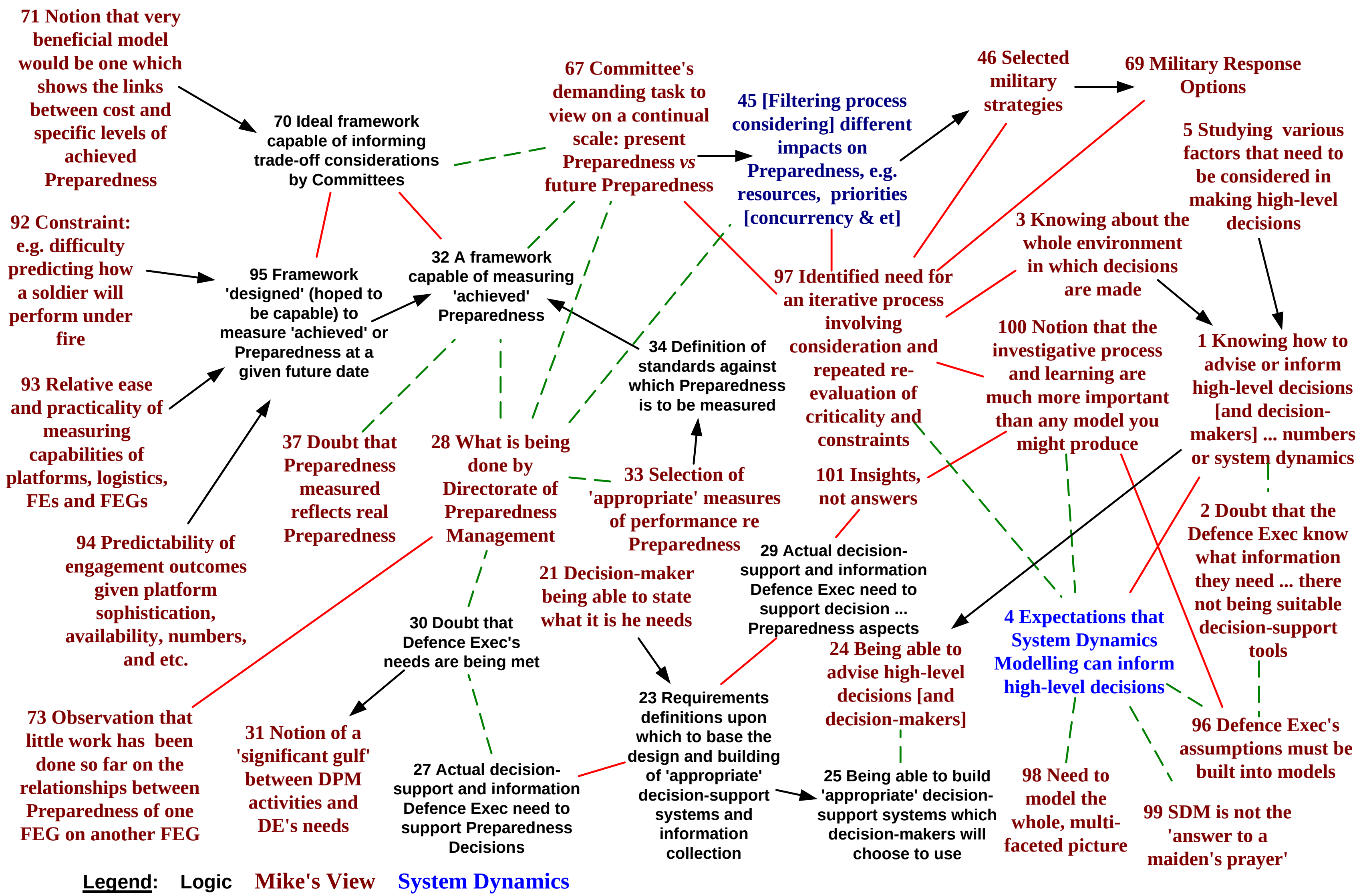

73 Observation that little work has been done so far on the relationships between Preparedness of one FEG and another FEG
72 Conviction that there is no really strong link between cost and preparedness we are trying to achieve
71 Notion that very beneficial model would be one which shows the links between cost and specific levels of achieved Preparedness
70 Ideal framework capable of informing trade-off considerations by Committees
32 A framework capable of measuring 'achieved' Preparedness
28 What is being done by directorate of Preparedness Management
74 [Consideration of] concurrency issues
75 You might be able to need two or three MROs but what happens if there are five: are there any other ways of doing that?
45 [Filtering process considering] different impacts on Preparedness, e.g. resources, priorities [concurrency & etc.]
49 Rejected military strategies (for possible future consideration)
46 Selected military strategies
44 [Initially unconstrained] Large numbers of military strategies developed
69 Military Response Options
47 Filtering criteria [unstated?]
53 Notion that DoD Capability Development has greater priority than Preparedness
68 Trade-off: lower short-term Preparedness to make money available to buy future Capability
67 Committee's demanding task to view on a continual scale: present Preparedness *vs* future Preparedness
Legend: Logic Mike's View System Dynamics

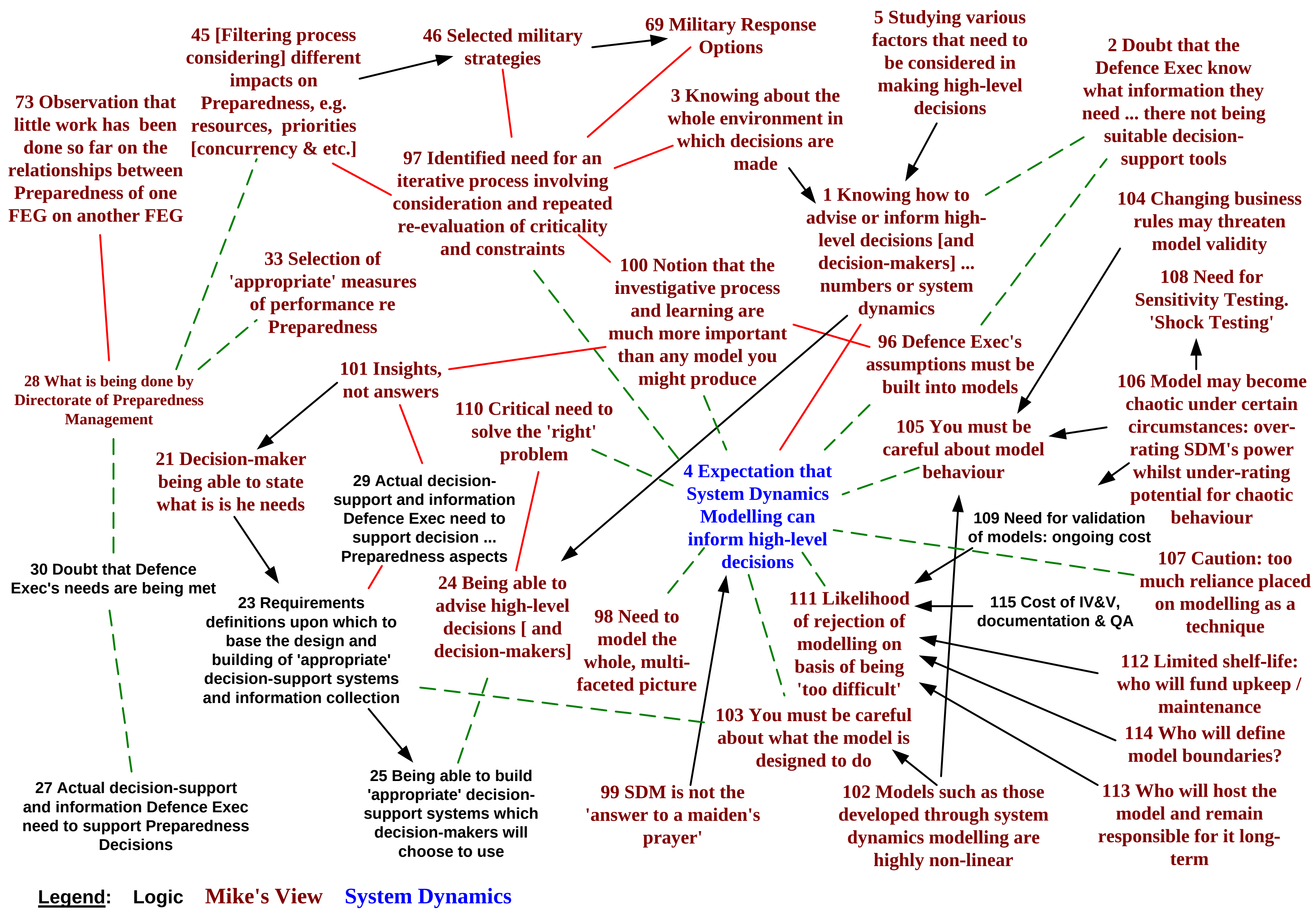


Legend: Logic Mike's View System Dynamics

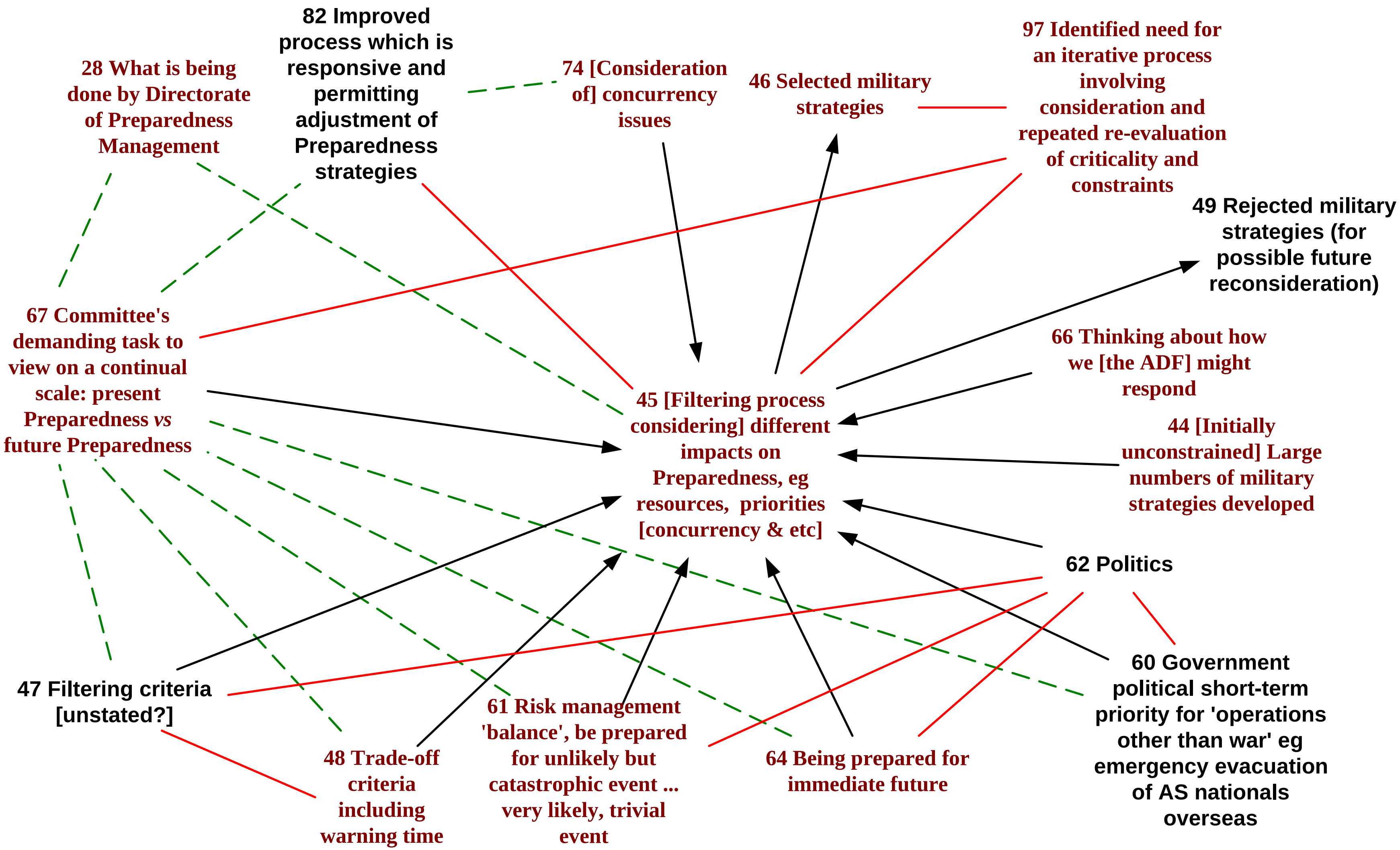

70 Ideal framework capable of informing trade-off considerations by Committees
71 Notion that very beneficial model would be one which shows the links between cost and specific levels of achieved Preparedness
72 Conviction that there is no really strong link between cost and preparedness we are trying to achieve
45 [Filtering process considering] different impacts on Preparedness, e.g. resources, priorities [concurrency & etc.]
46 Selected military strategies
69 Military Response Options
32 A framework capable of measuring 'achieved' Preparedness
47 Filtering criteria [unstated?]
85 Long procurement lead-times for Defence materiel
84 Notion that ADF is probably 90% of the force AS is is going to have in 10 years [in capability terms]
83 Extant investment in Major Capital Equipment (weapons platforms)
67 Committee's demanding task to view on a continual scale: present Preparedness *vs* future Preparedness
68 Trade-off: lower short-term Preparedness to make money available to buy future Capability
89 Funds available for better [more expensive] future platforms
88 Historically, Defence funding remains constant in absolute terms during peacetime
53 Notion that DoD Capability Development has greater priority than Preparedness
86 Spending on Preparedness now
87 Funds available for future platforms
90 Funds available for future Force Structure
91 Funds available for ongoing repair, maintenance, and upgrades
–
–
–
Legend: Logic Mike's View System Dynamics


71 Notion that very beneficial model would be one which shows the links between cost and specific levels of achieved Preparedness
70 Ideal framework capable of informing trade-off considerations by Committees
69 Military Response Options
92 Constraint: e.g. difficulty predicting how a soldier will perform under fire
95 Framework 'designed (hoped to be capable) to measure 'achieved' or Preparedness at a given future date
45 [Filtering process considering] different impacts on Preparedness, e.g. resources, priorities [concurrency & etc.]
46 Selected military strategies
32 A framework capable of measuring 'achieved' Preparedness
93 Relative ease and practicality of measuring capabilities of platforms, logistics, FEs and FEGs
94 Predictability of engagement outcomes given platform sophistication, availability, numbers and etc.
67 Committee's demanding task to view on a continual scale: present Preparedness *vs.* future Preparedness
Legend: Logic Mike's View System Dynamics


71 Notion that very beneficial model would be one which shows the links between cost and specific levels of achieved Preparedness
70 Ideal framework capable of informing trade-off considerations by Committees
67 Committee's demanding task to view on a continual scale: present Preparedness vs future Preparedness
45 [Filtering process considering] different impacts on Preparedness, e.g. resources, priorities [concurrency & et]
46 Selected military strategies
69 Military Response Options
5 Studying various factors that need to be considered in making high-level decisions
92 Constraint: e.g. difficulty predicting how a soldier will perform under fire
95 Framework 'designed' (hoped to be capable) to measure 'achieved' or Preparedness at a given future date
32 A framework capable of measuring 'achieved' Preparedness
97 Identified need for an iterative process involving consideration and repeated re-evaluation of criticality and constraints
3 Knowing about the whole environment in which decisions are made
1 Knowing how to advise or inform high-level decisions [and decision-makers] ... numbers or system dynamics
100 Notion that the investigative process and learning are much more important than any model you might produce
34 Definition of standards against which Preparedness is to be measured
93 Relative ease and practicality of measuring capabilities of platforms, logistics, FEs and FEGs
37 Doubt that Preparedness measured reflects real Preparedness
28 What is being done by Directorate of Preparedness Management
33 Selection of 'appropriate' measures of performance re Preparedness
101 Insights, not answers
2 Doubt that the Defence Exec know what information they need ... there not being suitable decision-support tools
94 Predictability of engagement outcomes given platform sophistication, availability, numbers, and etc.
29 Actual decision-support and information Defence Exec need to support decision ... Preparedness aspects
21 Decision-maker being able to state what it is he needs
30 Doubt that Defence Exec's needs are being met
4 Expectations that System Dynamics Modelling can inform high-level decisions
24 Being able to advise high-level decisions [and decision-makers]
73 Observation that little work has been done so far on the relationships between Preparedness of one FEG on another FEG
31 Notion of a 'significant gulf' between DPM activities and DE's needs
23 Requirements definitions upon which to base the design and building of 'appropriate' decision-support systems and information collection
27 Actual decision-support and information Defence Exec need to support Preparedness Decisions
25 Being able to build 'appropriate' decision-support systems which decision-makers will choose to use
96 Defence Exec's assumptions must be built into models
98 Need to model the whole, multi-faceted picture
99 SDM is not the 'answer to a maiden's prayer'
Legend: Logic Mike's View System Dynamics



45 [Filtering process considering] different impacts on Preparedness, e.g. resources, priorities [concurrency & etc.]
46 Selected military strategies
69 Military Response Options
5 Studying various factors that need to be considered in making high-level decisions
2 Doubt that the Defence Exec know what information they need ... there not being suitable decision-support tools
73 Observation that little work has been done so far on the relationships between Preparedness of one FEG on another FEG
3 Knowing about the whole environment in which decisions are made
97 Identified need for an iterative process involving consideration and repeated re-evaluation of criticality and constraints
1 Knowing how to advise or inform high-level decisions [and decision-makers] ... numbers or system dynamics
104 Changing business rules may threaten model validity
33 Selection of 'appropriate' measures of performance re Preparedness
100 Notion that the investigative process and learning are much more important than any model you might produce
108 Need for Sensitivity Testing. 'Shock Testing'
96 Defence Exec's assumptions must be built into models
28 What is being done by Directorate of Preparedness Management
101 Insights, not answers
106 Model may become chaotic under certain circumstances: over-rating SDM's power whilst under-rating potential for chaotic behaviour
110 Critical need to solve the 'right' problem
105 You must be careful about model behaviour
21 Decision-maker being able to state what is is he needs
29 Actual decision-support and information Defence Exec need to support decision ... Preparedness aspects
4 Expectation that System Dynamics Modelling can inform high-level decisions
109 Need for validation of models: ongoing cost
30 Doubt that Defence Exec's needs are being met
107 Caution: too much reliance placed on modelling as a technique
23 Requirements definitions upon which to base the design and building of 'appropriate' decision-support systems and information collection
24 Being able to advise high-level decisions [and decision-makers]
98 Need to model the whole, multi-faceted picture
111 Likelihood of rejection of modelling on basis of being 'too difficult'
115 Cost of IV&V, documentation & QA
112 Limited shelf-life: who will fund upkeep / maintenance
103 You must be careful about what the model is designed to do
114 Who will define model boundaries?
27 Actual decision-support and information Defence Exec need to support Preparedness Decisions
25 Being able to build 'appropriate' decision-support systems which decision-makers will choose to use
99 SDM is not the 'answer to a maiden's prayer'
102 Models such as those developed through system dynamics modelling are highly non-linear
113 Who will host the model and remain responsible for it long-term
Legend: Logic Mike's View System Dynamics



<u>Legend</u>: Logic Mike's View System Dynamics

ANNEX F: QUALITATIVE *VS* QUANTITATIVE MODELLING – SWOT ANALYSIS

SWOT ANALYSIS: COYLE'S RESEARCH AGENDA

F.1 Qualitative vs Quantitative Research Agenda Proposed by Coyle

Coyle (2000 stated):

> The first stage in system dynamics modeling is description of the system by some form of diagram. That is true whether one traces out many influences… or whether on starts by identifying some particular levels and then maps the feedback connections between them. The second stage is very likely to be a study of the diagram, if only during the process of checking its suitability for the problem. It is, therefore, only at the third stage that quantification arises so the research task boils down, as far as can now be seen, to two questions.
>
> The first is general and may apply to all models: 'how much value does quantified modeling add to the qualitative analysis?' Put another way, 'Qualitative modeling may be imperfect but is quantification always better?'… If, though, the questions are valid, they cannot be answered by anecdote, still less by didactic assertion that SD *must* involve quantification. Serious research into this first question is likely to involve some kind of metric for the added benefit from quantification in relation to the cost of the work. Since the metric will probably relate to understanding and confidence in recommendations, it will be necessary to have some sort of definition of 'understanding' to take us away from the glib repetition of 'insight'. In particular, it seems likely that it will be necessary to be clear about where the insight lies. Is it that the modeler found out something that the 'client', whether that is a fee-paying sponsor or a research community, already knew perfectly well?
>
> The second relates to… 'difficult models' [such as those involving 'soft' variables…]. A number of steps suggest themselves:
>
> - Identifying more precisely the types of models and the domains of investigation in which models are likely to arise.
> - Considering how ['soft'] variables… might acceptably be measured.
> - Attempting to establish principles for deducing that shape and values of non-linearities.
> - Developing a technique for handling non-linear effects on a given variable, so as to avoid double counting.

- Defining a procedure for establishing the forms of relationship involving multipliers, that is, whether factors are multiplicative, additive, minimizing or whatever.
- Some… difficult problems… involve parties that have conflicting objectives, are in discord or are even in violent conflict.
- Finding some formal measure of the extent to which uncertainties in formulating equations or obtaining data affect the reliability of the model (measuring variations from a reference mode by sensitivity testing guided by statistical design?) (Coyle 2000: 241-242).

F.2 Reviewing Achievements Against Research Agenda Proposed by Coyle

Whilst this thesis was not specifically designed to answer Coyle's questions, what Coyle asks provides a very relevant benchmark against which the results achieved by this research effort may be gauged. This research sought to integrate qualitative and quantitative techniques rather than to determine which are most effective, *per se*. SWOT analysis is applied as follows:

a. *Strengths* of research in providing a basis for answering the questions posed, or issue raised.

b. *Weaknesses* of research in providing a basis for answering the question posed, or issue raised.

c. *Opportunities* produce by the research effort, in respect of the question posed, or issue raised.

d. *Threats* emanating from the research effort, in respect of the question posed, or issue raised.

F.3 Value Added by Quantified Modelling

<u>Issue 1</u>*: How much value does quantified modelling add to the qualitative analysis?… Qualitative modelling may be imperfect but is quantification always better?*

<u>Strengths</u>: Further to Coyle (1996), 7.14 demonstrated a technique for identifying pressure points in influence diagrams. Pressure points become foci for application of management effort. Put simply, this is the basis for strategy development, using qualitative modeling. One example of how pressure point identification and analysis

leads directly to strategy development is at 7.13. The need to continually staff *ThreeTwoOne's* clerical office was identified as an essential part of a strategy, which set out to minimise the incidence of, lost orders. At the end of two half-day workshops, where a problem is addressed *ab initio*, it is reasonable to expect that remedial strategies could be developed on the basis of influence diagrams. By comparison, to build quantitative models for *ThreeTwoOne* enabling formulation of a recommendation regarding 'optimum' number of trucks, see Annex B, might involve 40-50 hours of modeling effort, over and above the two half-day workshops. So, in such cases, it is reasonable to expect that to build qualitative models upon which strategy can be developed could take 5-10 times longer to create than qualitative models. Quantitative modeling produced definitive strategies. The quantitative model permitted the creation of a number of quite specific strategies that could not have been derived from qualitative modeling. This was so in each of the cases where quantitative models were built.

The System Dynamics 'Front End' Tool applied to causal loop diagrams supports testing of logical structure enables the identification of pressure points and testing of the sensitivity to different strategies. The utility of causal loop diagrams has now been increased to the point where useful strategies can be derived, in many cases, without the need to build conventional quantitative system dynamics models. The gap between qualitative and quantitative modeling has been significantly reduced as a result.

<u>Weaknesses</u>: The ability to develop sound remedial strategies on the basis of influence diagramming seems strongly dependent on experience the modeler has in building system dynamics models. Separately, Sterman (1985) and Coyle (1996) make this observation. Also see 11.10. So, the potential for exploiting qualitative modeling may be difficult to determine on the basis that experience is difficult to measure. No attempt was made in his research effort to analyse the link between experience and ability to exploit qualitative modeling. Further, despite what might be inferred from the systems thinking literature, feedback structures are rarely obvious at first glance. Feedback structures are generally buried within the problem. Certainly for the novice, and for anybody seeing a problem for the first time, it is necessary to develop a real understanding of a problem situation before attempting any form of high level summarising. This is particularly important given that each problem in system dynamics

is unique. This was demonstrated through the case studies in Chapters 3 and 4, in the tutorial Chapter 7, and the various case applications in Chapters 8, 9 and 10.

Opportunities: Given that qualitative modeling comes first, considerable opportunity exists to make qualitative modeling as effective as possible. Given that qualitative modeling comes first, it is suggested that every effort would be made to make this as productive as possible. See 2.1. It was argued at Chapter 11, that first pass analysis using the SD 'Front End' tool and techniques would aid in directing data gathering activities, noting that gathering required data was an important factor militating against success in DPRM.

Threats: To launch directly into high-level qualitative analysis or quantitative analysis without firstly conducting qualitative analysis brings its own risks. This was demonstrated in Chapter 10. Chapter 10 also demonstrated that data needed to populate models might not be easily extracted from extant databases, particularly where models are built at higher levels of aggregation. Frequently SD models of higher levels of aggregation have greatest utility in strategy development.

Comment: Coyle's research agenda issue might be re-cast to include analysis of the relationship between system dynamics experience and skill required to develop sound qualitative models. Given findings by Sweeney and Sterman (2000) regarding human ability to mentally simulate or mentally calculate 'bathtub dynamics', it is suggested that human ability to simulate qualitative modes may be lacking. This is offered as a potential reason for aversion to qualitative modeling. It seems that many would rather build quantitative models through incremental and iterative processes than put their own mental faculties to the task?

Value is worth of results produced divided by cost of producing those results. Both worth and cost are expressed in dollar terms. Establishing worth involves using metrics pertaining to utility such as utility of learning that occurs or utility of strategy generated. In the latter case strategy must be implemented to have worth? Given the discussion above, we might hope that quantitative models will have considerably more utility for developing strategy than qualitative models. Whether 5-10 times more utility is produced, requires research. Alternatively, the client might expect much higher levels of confidence in quantitative models. However, qualitative models build on the basis of techniques described at Chapters 6 and 7 should provide confidence that a robust methodology exists and is capable of producing guidance regarding where best to apply management effort at least. That, in itself, is most important. It is relatively easy to build an argument that a quantitative modelling provides more robust analysis.

However, as it was found at Chapter 10, models based on available data may be narrowly focused whilst those at a higher level of aggregation, more suited to strategy development, may be difficult to populate. If they cannot be populated adequately or in the time required, they are unlikely to be acceptable to the client, regardless of how sound they are. There are two considerations here. Firstly, there is an issue of risk management in relation to the efficacy of modeling, qualitative or quantitative. Secondly, there is the issue of providing confidence to the client that the right problem has been addressed and that the recommended strategy is likely to produce the intended outcomes.

F4. Understanding and Insights

Issue 2: Identifying exactly where insights occur.

Strengths: In Chapter 2, the way decision-makers think was considered. It is argued that this is a logical start point because understanding how decision-makers think may provide an understanding how they react to insights, even if we cannot identify exactly where insights occur. Thinking about thinking, that is, metacognition is important to identifying how, where and why insights occur. Identifying when and how they occur might help understand what it is about our models that fosters the development of insights.

Weaknesses: The link between what insight, and where it occurs, remains unclear. Unraveling this will require a multi-disciplinary approach drawing on expertise from cognitive psychology. Assessing the utility of the insights remains within the domain of system dynamics.

Opportunities: Integrating qualitative and quantitative techniques such as advocated in Chapters 6 and 7 offers promise of a logical progression through the various stages of the system dynamics intervention process. With this logical progression, there may be better opportunities to exploit choice styles, learning styles and identify how insights develop in different clients and in varying problem domains.

Threats: Because a variety of systems thinking and system dynamics techniques are used, it becomes difficult to replicate how clients developed insights. There is strong argument for following standardized, proven system dynamics practices.

Comments: IISD has been built on the proposition that superior understanding leads to superior learning, noting that understanding is produced when insights occur. In Chapter 2, how decision-makers think was considered with the aim of identifying how insights develop, and, in turn, how that informs decision-making processes. A variety of ways of addressing a problem and fostering the creation of insights can only be employed if the analyst has a selection of effective qualitative and quantitative techniques to draw upon. The reaction of the stakeholders, as insights develop, can be gauged. In turn, this can inform choice of which techniques might be used to further improve the creation and exploitation of insights.

F.5 Types of Difficult Models and Domains of Investigation Where They Occur

Issue 3: Identifying more precisely the types of models and the domains of investigation in which difficult models are likely to arise.

Strengths: Nil.

Weaknesses: This research did not specifically address this issue.

Opportunities: The techniques used in the studies at Chapters 3 and 4 offer potential for use in analysis of various domains of investigation where difficult models arise.

Threats: Being able to analyse the domains in which difficult problems are likely to arise, is contingent upon the documentation of the cases. There are few example cases being documented to the extent necessary.

Comments: Nil.

F.6 Measurement of ‘Soft’ Variables

Issue 4: Consideration of how [‘soft’] variables might acceptably be measured.

Strengths: Treating soft variables the same way a risk factors, on a scale of 0 to 1, was demonstrated at Chapter 11.

Weaknesses: Nil.

Opportunities: Nil.

Threats: Nil.

Comments: The differences between parameters, variables, and notional concepts of parameters are not clearly enunciated in the literature. The differences are easier to appreciate and handle for ‘hard’ problems. Disciplined use of dimensional units will help. Dimensional models will be quantified SD models. Dimensionless models, by definition cannot be quantified. Treating the relationships between soft variables in the same way as risk factors, depicting them graphically on a scale of 0 to 1, was demonstrated at Chapter 11. Further investigation is needed.

F.7 Principles of Deducing Shape and Values of Non-Linearities

Issue 5: Attempting to establish principles for deducing the shape and values of non-linearities.

Strengths: The SD ‘Front End’ tool demonstrated at Chapter 11 provides utility to deduce the shape of non-linearities by trial and error, at least to an extent.

Weakness: Nil.

Opportunities: Nil.

Threats: Deducing the shape and values of non-linearities can be extraordinarily difficult when limited data is available. This problem is exacerbated as the level of aggregation is raised. Under these circumstances, as was shown in Chapter 10, special data gathering mechanisms need to be created. Often, this is impractical, too time consuming, or leads to organizational resistance. These contributed to the demise of system dynamics modeling in DPRM. See Chapter 10.

Comments: Considerable skill is needed to outline the shape of non-linearities and estimate values. Skill builds with experience as a system dynamics modeler. There are many opportunities to get the shape of non-linearities wrong. This was found during early attempts to initialize causal loop diagrams. See Chapter 11. The System Dynamics ‘Front End’ Tool demonstrated at Chapter 11 provides utility to estimate the shape on non-linearities, then test those estimates using trial and error.

F.8 Technique to Overcome Double Counting of Non-Linear Effects

Issue 6: Developing a technique for handling non-linear effects on a given variable, so as to avoid double counting.

Strengths: This was demonstrated at Chapter 11.

Weaknesses: In cases where feedback mechanisms are vague or difficult to identify, confidence in the results obtained through the use of SD 'Front End' tool could be low. The illicit drugs example at Chapter 11 may not be representative of a broad range of problems, including the 'difficult' types of problem identified by Coyle.

Opportunities: Development of the SD 'Front End' tool and associated techniques offers a new facility to test hypotheses regarding non-linearities.

Threats: The main threat is being able to analyse causal influences is to firstly create the influence diagram or causal loop diagram without error. Sterman (Richardson 1985) notes that even experienced modellers are misled by causal loop diagrams. Creating causal loop diagrams without error is not a trivial task. See Chapter 7.

Comments: Whilst the effect was not measured, it was observed that choices are frequently made on the presentation of a single cue; see *Take the First* heuristic at Chapter 2. Combinations of cues may be treated differently by different individuals, see work of Klein and Cooper at Annex A. How these effects apply to influences acting at a point or upon a parameter needs further investigation.

F.9 Establishing Algebraic Forms of Auxiliary Relationship

Issue 7: Defining a procedure for establishing the forms of relationships involving multipliers, that is, whether factors are multiplicative, additive, minimizing or whatever.

Weaknesses: The System Dynamics 'Front End' Tool now provides a vehicle for testing the veracity of the assumption that influences at a node in a causal loop diagram (influence diagram or cognitive map) are additive. Coyle (2000) and Nuthmann (1994) argue this assumption needs formal investigation.

Opportunities: Planned developments of the System Dynamics 'Front End' Tool will cater for a range of strategies for combing the influences at a node, but each will involve some form of addition.

Threats: Nil.

Comments: This was not specifically addressed and remains a limitation of the tool developed at Chapter 11. This issue described here by Coyle is one deserving greater attention than could have been addressed late in this research effort, and has broader implications for the system dynamics community.

F.10 Resolving Conflicting Objectives

Issue 8: Some… difficult problems… involve parties that have conflicting objectives are in discord or are even in violent conflict.

Strengths: Where conflicting objectives exist, employing IISD offers considerable promise. Employing IISD, as described at Chapter 7, helps manage situations where conflicting objectives, or discord, exist.

Weaknesses: Success depends on high levels of facilitative skills and familiarity with a wide range of techniques with which the client might feel comfortable.

Opportunities: Nil.

Threats: IISD is not designed for situations where violent conflict exists.

Comments: This research identified complicating effects of stakeholders with conflicting objectives, existence of systems of knowledge-power and barriers to addressing 'wicked' (difficult) problems.

F.11 Making Formulation of Equations More Certain

Issue 9: Finding some formal measure of the extent to which uncertainties in formulating equations or obtaining data affect the reliability of the model (measuring variations from a reference mode by sensitivity testing guided by statistical design?).

Strengths: SD 'Front End' tool offers the opportunity for first pass analysis of sensitivity of a problem to policy changes at identified pressure points. Another use of the System Dynamics 'Front End' Tool is to assist in identification of data sets to be gathered before quantitative models are built. It also offers the opportunity for comparison of results achieved through alternative approaches to problem analysis.

Weaknesses: This was not specifically addressed.

Opportunities: Nil.

Threats: Nil.

Comments: This is an issue for the broader system dynamics community to consider.