Achieving Systemic Information Operations for Australian Defence

R. J. Staker

Information Technology Division
Electronics and Surveillance Research Laboratory

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ABSTRACT

This document describes a proposed program of research into theories, methodologies and techniques appropriate to achieving a systemic Military Information Operations capability for the Australian Defence Force. The major expected outcomes of this research are decision support aids relevant to Information Operations, contributions to the theory of Information Operations and contributions to IO Policy and Doctrine. The doctrine would include matters relating to the design of organisations that are capable of operating effectively in an Information Operations environment.

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PO Box 1500
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Telephone: (08) 8259 5555
Facsimile: (08) 8259 6567

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EXECUTIVE SUMMARY

This document describes a proposed program of research into theories, methodologies and techniques appropriate to achieving a systemic Military Information Operations capability for the Australian Defence Force. The methodologies that are identified as of potential value include both so-called soft methodologies as well as rigorous quantitative methodologies. Soft methodologies are included in recognition of the fact that human factors are of pivotal significance in addressing the impact of Information Operations. In fact, it is proposed that soft methodologies play the primary role in analysis, with rigorous quantitative methodologies having only a subservient, but complementary, role. For example, they may be used to test the internal consistency and feasibility of conclusions arising from the application of soft methodologies. They may also assist in clarifying the implications of various available decision options.

The soft methodology that currently appears to be most applicable to Military Information Operations is Checkland's Soft Systems Methodology and some emphasis is placed on this methodology in the present document. Other soft methodologies also exist which may prove to be superior for specialised applications, or which may have complementary contributions to make. Therefore, part of the proposed research includes further investigation into such soft methodologies.

The reason for the pre-eminence of human factors in Military Information Operations is that such operations are concerned with Command and Control functions and processes. Human judgement is fundamental to Command and Control for a number of reasons. Perhaps the most basic of these is that it is ultimately a matter of human judgement whether one military end-state is more satisfactory than another. The task of making such an assessment could never in principle be delegated to a presently conceivable mathematical algorithm or machine, because it relies so intimately on human considerations, and also on the accountability of the human decision-maker.

Nonetheless, it should be possible for a machine to aid a human decision-maker to ensure that his decision is soundly based on all relevant considerations. One of the major outcomes from the proposed research is expected to be a family of decision support aids relevant to Information Operations. These are expected to be realised through an interplay of soft systems methodologies, rigorous analytical methodologies and traditional systems engineering. The traditional systems engineering aspects of the work would not in themselves constitute research and therefore it may be appropriate to arrange for parts of this to be performed by industry, under contract.

The other major expected outcomes, beside decision support aids are contributions to the theory of Information Operations and contributions to IO Policy and Doctrine. This doctrine would include matters relating to the design of organisations that are capable of operating effectively in an Information Operations environment.

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1 Introduction

Widespread concern exists throughout many advanced nations concerning the potential for Information Operations to adversely influence the outcome of Military Operations or adversely affect their national interests in other ways[5, 33]. This concern is shared by elements of the Department of Defence and other Australian government agencies. In order to ensure that any such potential does not adversely affect Australian interests, there is a need to develop an Information Operations capability for the Australian Defence Organisation.

This document outlines a program of research to explore methods through which such a capability could be achieved. In part, the term "systemic" is used in the title because it is proposed that the overarching methodology that will be adopted will be one chosen from the burgeoning field of soft systems theory, for example Checkland's Soft Systems Methodology (SSM)[8]. Such methodologies are regarded as systemic because they attempt to treat the phenomenon under study as a whole system, rather than a collection of individual components that may be studied in isolation.

Another, more important, reason for choosing the term is that, in order to be truly effective, Information Operations concepts must become instilled into the everyday business of all the relevant Defence agencies and ADF elements such that they become indivisible from the conventional aspects of their operations. The Information Operations capability then becomes an emergent property of an interacting collection of agencies. This capability will primarily be achieved through the better informed use of existing resources and equipment. It is anticipated that software tools can facilitate this. Adopting Checkland's terminology, this is the author's *"Weltanschauung"* which underlies the research that is proposed in this document.[1] A description of some research that the author has already performed in this vein is given in reference 29.

The next section provides a brief introduction to the field of Information Operations. Subsequent sections will describe the proposed research in more detail.

2 Information Operations

Many definitions of Information Operations exist. One such definition that is favoured by the ADF is:

"actions taken to defend and enhance one's own information and information systems and to affect adversary information and information systems".

Note that there is some debate concerning whether the definition should include the word "enhance". Reference 16 is understood to broaden this definition to explicitly include the processing and services performed by information systems. Another concept

[1] The word *Weltanschauung* has been adopted as a philosophical term into the English language from German. It literally means "world-view". Webster's Revised Unabridged Dictionary (1913) defines it as "a conception of the course of events in, and of the purpose of, the world as a whole, forming a philosophical view or apprehension of the universe". Checkland uses the term in a more technical sense to mean those aspects of a complete *Weltanschauung* relevant to the problem situation.

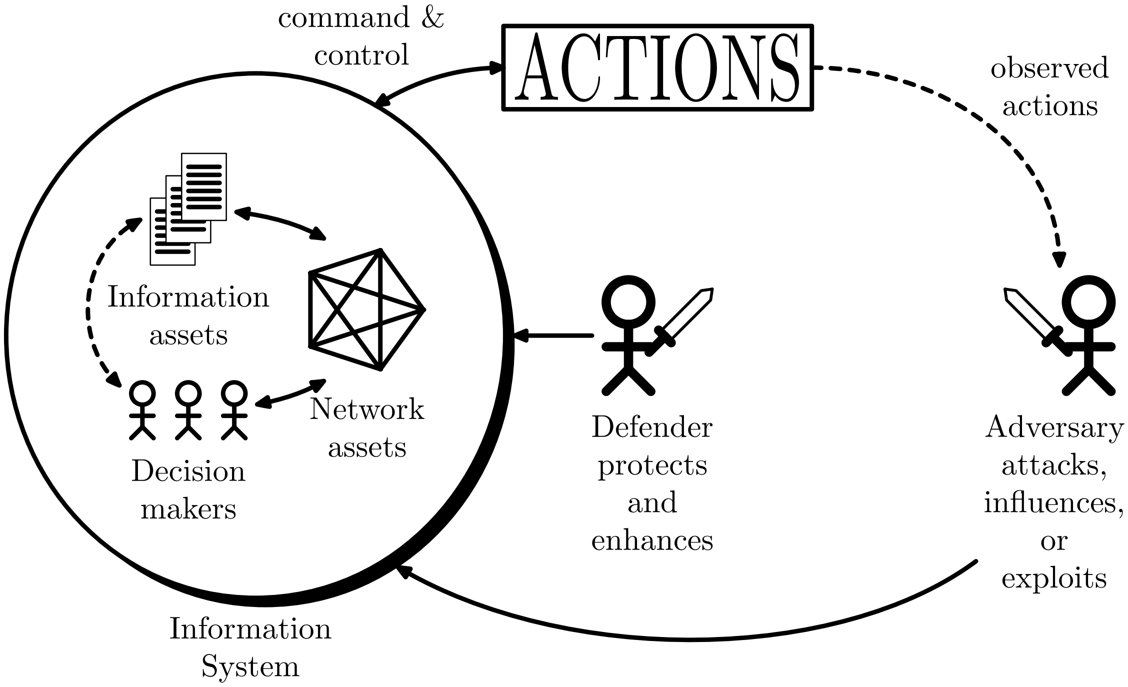

Figure 1: Rich Picture for Information Warfare

closely related to Information Operations is that of Information Warfare. The distinction between the two is not clear in the literature, however there appears to be a trend towards regarding Information Operations as the general term, with Information Warfare referring to offensive and defensive Information Operations that occur during times of rising tension and of war.

Military Information Operations are a specific class of Information Operations which focus on the decision-making aspects of warfare and military operations other than war (OOTW). There can be considered to be three aspects to such operations: attack, defence and support. The objective of offensive operations of this kind is to influence an adversary commander's ability to accurately direct his forces in a timely manner, and hence to affect his warfighting effectiveness, ideally to such an extent that he is forced to capitulate. On the other hand, the objective of defensive operations is to protect the decision-making processes of friendly commanders from such attack. Support operations are common activities required for both attack and defence. Military Information Operations are aimed at achieving a satisfactory outcome from a military conflict situation as expeditiously as possible, while minimising casualties and destruction. They are also undertaken outside of conflict in order to maintain readiness to undertake or defend against hostile information operations.

Figure 1 shows the roles involved in Information Warfare and the relationships between them. In Soft Systems Methodology, such a diagram would be termed a "rich picture" of the problem situation. Soft Systems Methodology is discussed in more detail below in section 4.1. The need to defend against naturally occurring incidents and imperfections also needs to be considered, but is not represented in the diagram, for the sake of clarity. Note that, in this particular context, the term "information system" is intended to apply in its broadest sense. The network assets referred to could be either technological or humanistic, and the same applies to the information assets. An interesting example of an early information system is that described in Chapter 5 of reference 7, which is the radar information system employed by the British Fighter Command during the Battle of Britain in World War II.

In addition to Military Information Operations, Information Operations may occur in a broader context. Such operations are aimed at securing national interests and maintaining peace, order and prosperity. Reference 36 provides a more detailed account of Information Operations and Information Warfare.

3 Proposed Research

The research will develop a theory of Information Operations which will form a foundation for contributions to information operations policy and doctrine. In addition, the research will seek to discover analysis, planning and management techniques that are applicable to Information Operations and Information Warfare, and to identify the specific techniques best suited and most appropriate to particular aspects of IO. The techniques to be considered fall into two broad categories, as described in the next section. The expected results of the research are described further in section 3.2.

3.1 Techniques

The first category of techniques consists of those from soft systems theory and soft operational research. An example of such a technique is Checkland's Soft Systems Methodology mentioned earlier. Some further details of this methodology can be found in section 4.1. A number of other soft techniques are described by Flood[12]. The primary purpose of these techniques will be to influence the structures and practices of relevant Defence organisations so as to achieve an effective and efficient Information Operations capability for the ADF. They will also assist in identifying the needs for supporting technical products and in identifying the user requirements for these. Furthermore, soft techniques will be studied for potential applications in planning and conducting Information Operations.

The second category consists of more rigorous techniques based on mathematical logic, probability theory and related areas of mathematics and computing science. These will form the components of the technical products required to support an IO capability, as described in section 3.2.4.

3.2 Results

The results of the research will fall into four general areas. They are:

- a theory of Information Operations that is tailored to the requirements of the ADF;
- contributions towards IO policy and doctrine for the ADF;

- a taxonomy of techniques according to the areas of IO to which they are most applicable; and

- technical products to support IO conducted by the ADF.

These areas are addressed individually in the next four sections.

3.2.1 Theory

A theory of Information Operations that is suitable for use by the ADF will be developed that is based on the combined application of both the soft and rigorous techniques. An example of a theory for information systems in general on which such a theory might be modelled is given in reference 7. Whereas that theory concentrates on soft aspects, the proposed theory would include both soft and rigorous aspects.

3.2.2 Policy and Doctrine

Contributions to policy and doctrine will be developed through application of the theory discussed in section 3.2.1. Application of soft techniques will entail significant interaction with the pertinent organisations within the ADF. A comprehensive record will be maintained of the issues raised and the outcomes achieved. The issues and outcomes will be summarised and the key points will be identified so that they may be incorporated into IO policy and doctrine as appropriate. The considerations leading to the identification of needs and requirements for supporting technical products will also be recorded.

3.2.3 Taxonomy of Techniques

A taxonomy of the techniques that are considered to be relevant to Information Operations will be developed that, for each technique, identifies the aspects of IO to which it is most suited. Canonical formulations will be developed and examples of the application of these will be given. In some cases, the examples will include the development of supporting technical products which are based on the techniques concerned.

3.2.4 Supporting Technical Products

As mentioned in passing in section 3.2.2, needs and requirements for supporting technical products will be elicited as one of the outcomes of the application of soft techniques. The paragraphs below describe how the development of research prototypes of such products will be influenced by these. Development will not be so onerously constricted by lack availability of directly elicited requirements as to be unable to provide for timely completion of prototypes. Where requirements are difficult to obtain directly, predicted requirements will be employed.

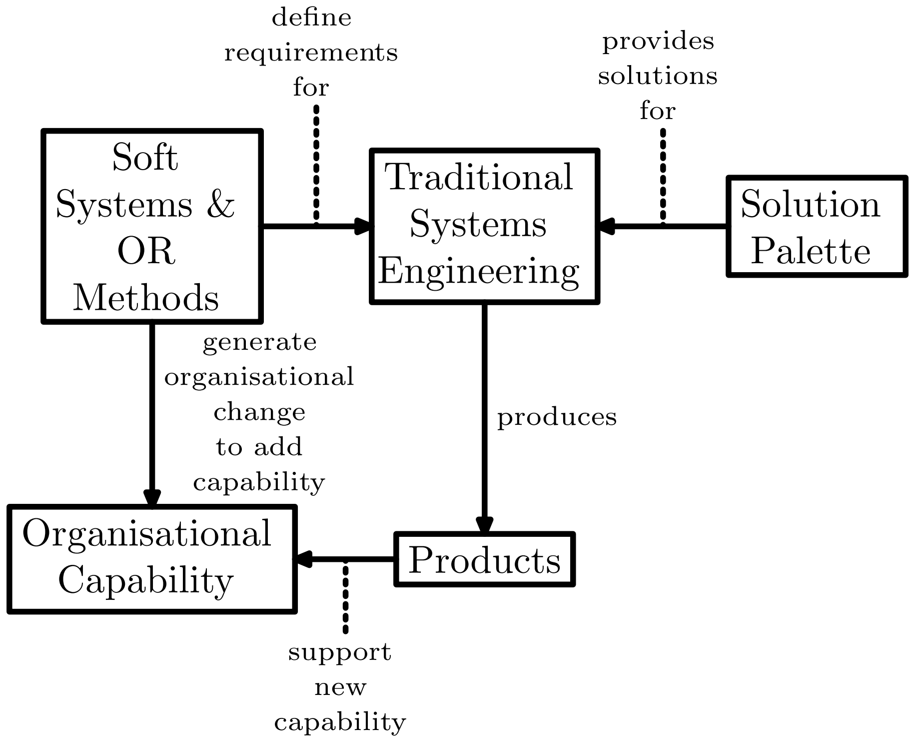

Figure 2: Proposed Development Method

Development Philosophy Traditional systems engineering is usually applied as a top-down procedure, with the effort of developing solutions deferred until requirements are firmly established. In this case however, there are several factors militating against a completely "top-down" approach. Some of these are the fluidity of the recently developed concept of Information Operations and the relative haste with which it is sought to introduce these concepts into operations. These mean, firstly, that a rigidly defined solution may become obsolescent as perceptions and definitions change in future, and, secondly, that too great a latency would be introduced by the top-down development process to be able to provide a timely solution. Consequently, there would be a risk that less desirable, but immediately available options might be seized upon.

Two measures will be adopted which seek to overcome these difficulties. The first of these will be to adopt a *predictive development* stance, as described further below. The second will be the adoption of a degree of "bottom-up" development. This bottom-up development will provide a palette of partial solutions which can be rapidly combined with one another in order to meet elicited or hypothesised requirements. The proposed development method is summarised in figure 2.

Since the research will be undertaken in the Information Technology Division of DSTO, the solutions will, of necessity, tend to be of a software or information technology nature. However, where requirements for other types of technological solution are found, these can be identified and pursued through collaboration with other DSTO Divisions.

Predictive Development In order to provide timely solutions, it will be necessary to perform some product development in advance of agreement being achieved on a clear set of requirements. This means that possible, or likely requirements will need to be anticipated in order to develop research prototype products. These research prototypes can then be demonstrated or trialed in order to assist study participants to clarify their real requirements, by examining how well the postulated requirements meet their needs. To facilitate such prototyping, it will be necessary to develop a solution palette from which research prototype products can be rapidly developed. Some components that might be contained in such a palette are discussed in section 4. In addition to the solution palette, a test environment, in which to demonstrate research prototypes, will be required. This environment could be provided by DSTO's Experimental C3I Technology Environment, also known as EXC3ITE[2]. The test environment might also employ DSTO's Distributed Interactive C3I Effectiveness (DICE) simulation to model C3I systems and provide a capability to immerse prototype products within synthetic environments able to support interactive experimentation[14].

Thus far, a number of possible requirements have been identified. They are listed below as examples of predicted requirements.

- Means for the assessment of the value of information assets to decision-making organisations.
- Means for the detection of vulnerabilities in information system networks, for risk analysis of those vulnerabilities, and for the implementation of measures to ensure that risk is held to acceptable levels.
- Means for comparing the relative effectiveness of various kinds of Military Information Operation, and also for comparing the effectiveness of such information operations with that of alternative conventional operations.
- Means for planning Military Information Operations. A particularly challenging aspect of this is the ability to accommodate uncertainty in developing the plan.

Refinement of these, and the identification of additional requirements, will be achieved through application of appropriate soft systems or operations research methodologies, as discussed further in section 4.1. A range of possible rigorous techniques that might be applied to meeting the requirements listed above, and any others which may be identified in the course of the research, are described in section 4.2. That section includes a number of concrete examples of how some of the methods have been applied either by the author, or by others, to either satisfying the requirements that were listed above, or to other problems relevant to Military Information Operations.

4 Solution Palette

This section is only included to illustrate to the interested reader the scope of the proposed research into solution techniques by listing a number of pertinent techniques and providing some concrete examples of their possible applications. The general thrust of the research has already been delineated in the preceding section.

The range of techniques that will be drawn upon and enhanced or adapted to satisfy the objectives of the research will be referred to as the "solution palette". It can be expected to grow in extent as the research proceeds and identifies additional techniques that should be included. It may also be the case that, with the passage of time, some of techniques included in the sections below come to be seen as less relevant. The precise composition of the solution palette may therefore fluctuate during the course of the research.

The conception is that the components of the solution palette can be developed with a very loose connection to the end user's requirements because they do not provide end products themselves, merely the components out of which solutions may be rapidly constructed when requirements come to be defined with sufficient precision.

4.1 Soft Techniques

A *complex system* can be characterised as one which comprises many interacting parts, such that a change affecting any one part has a propagating effect influencing many other parts, in an unpredictable manner. Organisations involving interacting groups of people invariably have a complex nature. Such an organisation is *pluralistic* when groups within it have diverging interests and aspirations. Soft techniques seek to address these *complex human activity systems* in a methodical manner. The adjective "soft" is used to emphasise that rigorous and objective problem definitions cannot be found.

The Total Systems Intervention approach of Flood and Jackson[12] provides a *meta*-methodology for selecting a systems analysis methodology. It divides problem situations into a number of categories ranging from *Simple-Unitary* to *Complex-Pluralistic*. The Military Information Operations problem situation may be regarded as lying at the complex-pluralistic end of this spectrum. This is suggested by the following considerations. Firstly, the ADF must be regarded as a "system of systems". Some obvious examples of the systems of which it is composed are the individual service components, the Army, Air Force and Navy. There are also many other less obvious examples, but this point will not be belaboured further here. Each such system within the overall ADF system has its own cherished traditions and culture. The introduction of a new capability may result in conflicts between these cultures. When such internecine conflicts arise, there must be some means by which an accommodation can be reached between the dissenting parties. In fortunate cases it may be possible to achieve agreement between the parties, but, commonly, the best that can be hoped for is mere accommodation and tolerance. The arbitrary imposition of a solution is most likely to lead to enduring tensions and feuding between the dissenting parties, with greatly diminished efficiency, and with a significant fraction of effort being expended in each party undermining the efforts of other parties. Thus, a coercive system entrenching this state of affairs would be highly undesirable.

Checkland's Soft Systems Methodology[6, 8, 37] is one of the methodologies that the Total Systems Intervention *meta*-methodology recommends for studying such complex-pluralistic systems. Checkland's methodology is summarised in figure 3. It accommodates

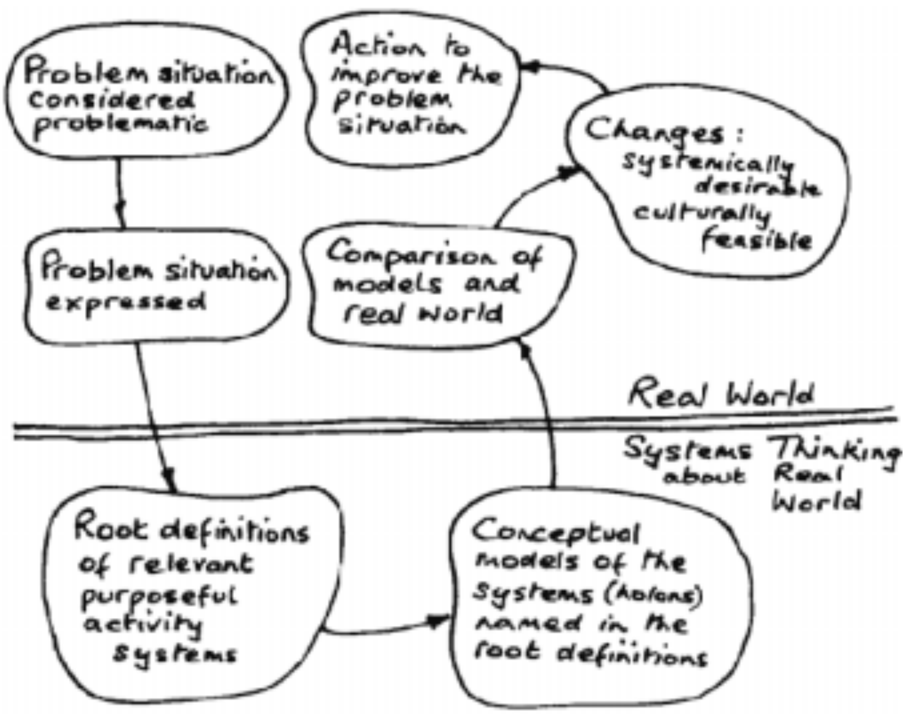

Figure 3: Soft Systems Methodology (after Checkland[8])

subjectivity by not insisting that there should be a single definition of a problem. Instead, it permits a number of definitions, and explicitly associates a subjective world-view or *"Weltanschauung"* with each one.

Another reason for considering Checkland's methodology an appropriate choice is that it has its roots in the concepts of traditional systems engineering, with which the military is already conversant, from its application to the acquisition of complex military systems. (Reference 3 describes traditional systems engineering in detail.) It is anticipated that, by adopting Soft Systems Methodology, the transition to traditional systems engineering, to support the acquisition of physical devices or other products, can be eased. These physical devices and other products would contribute to the realisation of actions suggested through application of Soft Systems Methodology.

Other indications for adopting soft techniques are that the Information Operations environment is fluid by nature, that requirements are unclear, and that, as indicated above, even definitions in the area are uncertain, let alone it being possible for all parties to envisage a solution. Finally, such a capability has little precedent. All of these factors provide ample scope for a variety of opinions to be held by the various organisations that form the ADF system-of-systems, and for rivalries and dissenting opinions to arise among them over aspects of the new field of Information Operations. Soft systems methodology provides a paradigm for resolving such differences.

As noted earlier, as well as being considered a suitable technique for guiding an IO capability acquisition process, Soft Systems Methodology may also have a role as a tool for planning and conducting Information Operations. The proposed research will also examine this possibility.

While most attention has been focussed on Checkland's Soft Systems Methodology in this section and in this document as a whole, the research will also investigate whether other soft systems and soft operation research methodologies exist that can be applied to problems in the IO domain.

4.2 Rigorous Techniques

In addition to the soft techniques described above, the solution palette will also contain components that are based on the more rigorous techniques described in the following sections. By the term"rigorous techniques" is meant techniques which are based on a solid mathematical or logic foundation. Because these demand rigour in defining assumptions, constructing models and in interpreting results, it is difficult for those lacking an intimate familiarity with them to be able to work directly with them. For this reason, soft techniques are employed to provide a comfortable access route for the non-specialist.

Additional applicable techniques are expected to be identified in the course of the research. Products developed using these techniques as components will be applied within the problem situation to meet the needs that have been identified using soft systems methods discussed above. A number of basic methods are described first, followed by a discussion of some ways in which these methods might be combined.

4.2.1 Basic Rigorous Techniques

The basic techniques described in this section comprise decision theory, expert systems, Fuzzy Logic, formal methods, Genetic Algorithms, graph theory, intelligent software agents, and dynamical system theory (including System Dynamics).

Probability Theory, Utility Theory and Decision Theory A number of techniques based on these theories appear to applicable, in particular Bayesian Belief Networks (BBNs) and Influence Diagrams (IDs). These are closely related techniques that seem to have a very broad range of potential applications, and to subsume a number of earlier techniques, for example, decision trees. One particularly important application of influence diagrams appears to be in placing an operational value on items of information. Using influence diagrams to compute the operational value of information seems to be a natural extension of Shannon's information theory[27] to the case where different values are associated with different outcomes. BBNs appear to be useful for performing risk assessments related to IO. For example, the author has used BBNs to model information system risk, as described in references 30 and 31.

Another possible application may be in cognitive modelling. Psychologists sometimes employ a technique called "Structural Equation Modelling"[11] for this purpose, as illustrated, for example, by reference 34. It would appear that such models are, in effect, a special case of Bayesian Belief Networks in which the probability distributions involved are all assumed to be multi-variate Gaussian distributions. There would seem to be some scope, therefore, for combining the merits of these two techniques. This may lead to a cognitive modelling method that can be used in applications such as IO planning and "battle damage" assessment.

Expert Systems Expert systems are traditionally used to capture human reasoning and decision-making processes, hence it may be expected that they will have a role to play in the context discussed here. They are complementary to other techniques such as Bayesian Belief Networks in that they represent knowledge explicitly as a set of rules. On the other hand, in a Bayesian Belief Network, knowledge is tacit and is encoded into conditional probability distributions. This dichotomy is reminiscent of that between conscious and intuitive reasoning in human beings. We may introspect upon our conscious reasoning, but our intuitive reasoning processes are hidden from us. Both types of reasoning are evidently important to us as human beings. By analogy, both techniques can be expected to have a role to play in the development of tools in the current context, perhaps as a combination, acting in concert.

Some other reasons why expert system techniques are applicable are their suitability for non-deterministic problems and their inherently modular nature. They are also inherently "systemic" in that it is difficult to fully predict their behaviour from a knowledge of the individual rules which they comprise, because of the non-deterministic property of these. This characteristic is usually regarded as a disadvantage. An example of an expert system shell that is freely available, and which has been used by the author for some of the work mentioned in this document, is given in reference 28.

Fuzzy Logic For the applications considered here, Fuzzy Logic contends with Bayesian Belief Networks. The theory of Fuzzy Logic is founded on the notion of a set membership function that can take a continuum of values between zero and 1.0, with zero indicating no membership at all, 1.0 indicating complete membership, and intervening values indicating intermediate degrees of membership. These intervening values are often associated with subjective perceptions, perhaps determined through sampling of the opinions of some group of people. When this is the case, there is clearly a close connection between Fuzzy Logic and probability theory, since the set membership function is simply the empirical probability distribution of the beliefs of a group of people. The significant difference is the manner in which these values are combined to compute the values associated with logical propositions concerning the random variables associated with these distributions. In probability theory, the values are combined in accordance with the laws of probability (Kolmogorov's axioms). In fuzzy set theory, values are combined by taking the maximum value of two elements when they are combined disjunctively, and their minimum value when they are combined conjunctively.

Drakopoulos[10] identifies the essential trade-off between Fuzzy Logic and probability theory. He classifies several schemes for representing uncertainty, including these two, according to their expressiveness, i.e., the extent to which one can be used to simulate the other. He proves probabilities to be more expressive than fuzzy sets, and that, while fuzzy sets can be used to simulate probabilities, the required storage space becomes exponentially large compared with that required when probabilities are used. On the other hand, fuzzy sets are more readily computable than probabilities, consequently the most appropriate choice to use will depend on the demands of the application. Thus, fuzzy sets have a place in the solution palette.

Fuzzy Logic is sometimes employed within expert systems, with the matching of rule right-hand sides with facts being performed on a fuzzy basis, and with certainty factors being associated with facts to indicate the degree to which they are believed to hold. Reference 25 describes one such system that is readily available.

Formal Methods Formal methods are based on symbolic logic and abstract systems. Their goal is to construct formal proofs of certain system properties. Examples of such properties are safety or security properties of software-controlled systems. Software is a good object for study by formal methods since it is not subject to external influences and does not change with time, unless intentional modifications are made to it. Formal methods are also suited to studying abstract concepts. They are less suited to studying objects in the physical world, however, because the assumptions on which proofs would be based cannot be readily guaranteed, and because no two physical objects are ever really identical. Statistical methods would usually be more appropriate in this case. Although they also entail making some assumptions, if properly applied they can make allowance for the uncertainty encountered in the physical world, while continuing to yield useful results. An example of the application of formal logic to the proof of software security properties is given in reference 21.

Another kind of formal method that is relevant to the work is that of Petri Nets[18]. These are primarily a graphical representation of events and the conditions required for their occurrence that succinctly incorporates modelling of resource requirements and conflicting demands for these. Various extensions to the basic Petri Net notation provide a more powerful modelling environment. Such extensions can include adding timing information to the net, so that it can also be used as a dynamical[2] model, in addition to a purely logical one. Petri Nets may be used for modelling organisational processes, including those which occur in military organisations. For an example of this, see reference 20. A readily available tool that supports various types of analyses involving Petri Nets is described in reference 22. Petri Nets also have more technical applications than those just cited, such as detection of intrusions into computer systems as described in reference 19. In addition, the DICE simulation[14], mentioned earlier, is able to employ extended Petri nets in the modelling of C3I system and other behaviour. This tool could be employed to create immersive simulations using Coloured Petri Net models that are developed in the course of the research. Such simulations, as well as being useful for demonstrating the effects of Military Information Operations, could also be of assistance in refining the models on which they are based, to enhance their fidelity.

Cellular Automata [32] are yet another type of formal representation which may find some application. These consist of a uniform array of cells, in a line, plane or in a higher-dimensional space. The contents of these cells are determined iteratively from their initial contents by the application of a set of rules. These rules apply more or less uniformly to all of the cells in the array, and specify the contents of the cell for the next step based on the present contents of related cells. The rules may be deterministic, as just described, or alternatively, specify probabilities for a number of different possibilities. A possible application would use the cells to represent information assets, and the contents might represent the extent to which they have been tainted by an information attack.

[2] The adjective "dynamical" is used here to indicate that the model includes the dynamic features of what is being modelled, rather than using "dynamic" which would tend to suggest that the model itself was subject to change.

Genetic Algorithms Genetic Algorithms [15, 23] are essentially *Monte Carlo* algorithms that are inspired by Darwin's Theory of Evolution and his principle of natural selection. Of course in the case of Genetic Algorithms, we rely on *unnatural (artificial) selection*. This is achieved through the specification of a *fitness measure*, which indicates how well a randomly selected candidate solution meets desired requirements. Candidate solutions correspond to individuals in Darwinian theory and these are specified by means of a *genome*, an artificial construct which encodes the unique features of the solution. New solutions are generated through the processes of *recombination*, where features from two existing genomes are combined, and *mutation*, where a few features are randomly altered. The reproductive rate of individuals is determined by their fitness measure, hence the fitness of the population is expected to increase through successive generations. The algorithm is terminated after a certain number of generations, or once a specified level of fitness is achieved. Genetic Algorithms provide a practical method for finding good solutions to combinatorial optimisation problems and hence have an important place in the solution palette.

Graph Theory Graph theory is implicit in many of the techniques that have already been mentioned. It is the basis of efficient algorithms for computing conditional and marginal probability distributions in Bayesian Belief Networks as described by reference 24. It is also the basis for ordering rule firing in expert systems, through the Rete algorithm, as well as that for the analysis of Petri Nets. Graph theory has an explicit role to play when analysing distributed decision-making organisations, since a network of interconnected decision-making nodes may be represented as a graph. Such explicit use of graph theory has been employed by the author in some recent research described in reference 30. This work was based on the use of abstract path algebras as described in reference 4. The particular path algebra that was applied was one which enabled calculation of the proper separating arc sets of a graph.

"Intelligent" Software Agents Intelligent software agents are becoming an increasingly important software technology for supporting distributed decision-making. They also have a role in distributed system management. Intelligent software agents are so named because they operate with limited direction from human operators and frequently employ artificial intelligence techniques to achieve goal-directed behaviour. Some agents are "mobile" in the sense that they may move between execution nodes in an information systems network to be closer to the source of information that is of greatest importance at any particular time. The result of doing this can be that network traffic is reduced and that disruptions to the network tend to have less impact on the operation of the agent. Of course, for this to be worthwhile, the size of the agent execution code and state information must be small in comparison with the amount of information they need to access to perform their task. Thus, a typical application for this concept would be one where the agent needed to search through a number of large databases for some small items of information. Such an application represents a generalisation of the prevalent client-server paradigm for distributed databases. In addition, agents can be endowed with the ability to communicate with their brethren, resulting in multi-agent systems that can exhibit cooperative behaviour. Speculatively, it might be possible to create complicated systems of cooperative agents that would behave in ways analogous to the various types of cell forming the human immune system and be able to remove undesirable malicious information or software processes from an information system network. Still more speculatively, some have suggested that genetic programming techniques, which are similar to the genetic algorithms described above, except that there is no explicit genome involved, could be used to evolve populations of agents for protecting information system networks against unauthorised intrusion. For example, see reference 9. Intelligent software agent technology should be included in the solution palette because of the distributed nature of decision-making in the Australian Defence Organisation.

Dynamical Systems Theory Dynamical systems are those which evolve with time. The quite recent realisation that the majority of dynamical systems do not possess regular solutions has led to the rise of chaos theory. Chaotic systems have dynamics such that a small perturbation to the system can lead to a solution that differs profoundly from that for the unperturbed system after a short evolution period. The salutary lesson from this is that it is the exceptional case to be able to predict the evolution of a dynamical system, even when the initial conditions and the rules governing its evolution are known to a high degree of accuracy. For the cases where it is meaningful to do so, there are a number of techniques available for integrating the state equations of dynamical systems. An example of the application of dynamical systems theory to conventional combat is given in reference 17.

Systems Dynamics System Dynamics [13, 26] is a methodology for the study of society, business operations, manufacturing and the like through simulation of the systems perceived to be at work in them. It is more a soft methodology than a rigorous one. The goal of the methodology is not to precisely predict the behaviour of a real world entity, but rather to explore the typical behaviours of conceptual models that we may have created in our minds, and how these behaviours depend on significant model parameters. It is included in this section, however, because it employs rigorous mathematical techniques to calculate the dynamic behaviour of the system under investigation.

4.2.2 Combinations of Rigorous Techniques

Various combinations of the basic techniques described above may be appropriate. For example, Wagenhals[35] shows one means by which influence diagrams can be combined with coloured Petri Nets by implementing the message-passing probability propagation algorithm as a Coloured Petri Net. Another way in which the two techniques can be combined is one which the present author has employed, where an Influence Diagram tool is used to generate a decision table, which is then employed in a Coloured Petri Net model.

Another possible combination of techniques is that described by Agosta[1]. Here, Influence Diagrams are combined with generative planning techniques in order to perform a certain type of bounded optimality planning under uncertainty. Generative planners are a kind of expert system for producing feasible plans for achieving some particular goal.

The author has recently explored the use of Bayesian Belief Networks in combination with a graph-theoretic technique for computing the minimal separating arc-sets of a graph, to develop a risk assessment tool for information system networks. This is described in a technical report[30], and also, more briefly, in a paper presented at the 1999 Information, Decision and Control Conference (IDC99)[31]. The concept could further be combined with genetic algorithm techniques to develop a tool for selecting a good set of countermeasures when resources are constrained.

5 Conclusion

The object of the research described here is to make a significant contribution to the achievement of a more effective and efficient Information Operations capability for the defence of Australia and of its interests. This will be achieved through developing a suitable theory of Information Operations, through making contributions derived from this theory to ADF IO policy and doctrine, through identifying techniques suitable for supporting the planning and conduct of IO, and through the development of a number of technical support products, in the form of software aids, that are based on these techniques.

References

1. Agosta, J. M. (1996) Constraining influence diagram structure by generative planning: An application to the optimization of oil spill response, *in* 'Proceedings of the Twelfth Annual Conference on Uncertainty in Artificial Intelligence (UAI–96)', Portland, Oregon, pp. 11–19.

2. Bingham, D. (1997) 'Experimental C3I technology environment (EXC3ITE) capability and technology demonstrator', published on the World-Wide Web. URL — `http://www.dsto.defence.gov.au/esrl/takari/information/takexct6.html`.

3. Blanchard, B. S. & Fabrycky, W. J. (1998) *Systems Engineering and Analysis*, 3rd edn, Prentice-Hall International, Inc.

4. Carre, B. (1979) *Graphs and Networks*, Oxford Applied Mathematics and Computing Science, Oxford University Press.

5. Cebrowski, A. K. (1996) *Information Warfare: Legal, Regulatory, Policy and Organizational Considerations for Assurance*, 2nd edn, The Joint Staff, United States Department of Defense, Washington D.C., 20318-6000, USA.

6. Checkland, P. (1981) *Systems Thinking, Systems Practice*, John Wiley & Sons.

7. Checkland, P. & Holwell, S. (1998) *Information, Systems and Information Systems - making sense of the field*, John Wiley & Sons.

8. Checkland, P. & Scholes, J. (1990) *Soft Systems Methodology in Action*, John Wiley & Sons.

9. Crosbie, M. (1995) Active defense of a computer system using autonomous agents, Technical Report 95-008, Department of Computer Sciences, Purdue University.

10. Drakopoulos, J. A. (1994) Probabilities, possibilities, and fuzzy sets, Technical Report KSL-94-40, Knowledge Systems Laboratory, Stanford University.

11. Duncan, O. D. (1975) *Introduction to Structural Equation Models*, Academic Press.

12. Flood, R. L. & Jackson, M. C. (1991) *Creative Problem Solving*, John Wiley & Sons.

13. Forrester, J. W. (1961) *Industrial Dynamics*, Productivity Press.

14. Gabrisch, C., Bowden, F. D., Davies, M., Haydon, N. A. & Winkles, J. (1999) Synthetic environment support to Air Asset Visualisation Tool development, *in* 'Proc. SimTecT99 Conference, Australia, 29 Mar – 1 Apr 1999', pp. 281—288.

15. Goldberg, D. E. (1989) *Genetic Algorithms in Search, Optimisation and Machine Learning*, Addison-Wesley.

16. Information Strategic Concepts Branch (1998) *IO Concept Paper No. 4: Information Assurance*, Strategic Command Division, Australian Defence Headquarters.

17. Ingber, L. (1993) Statistical mechanics of combat and extensions, *in* C. Jones, ed., 'Toward a Science of Command, Control, and Communications', American Institute of Aeronautics and Astronautics.

18. Jensen, K. (1997) *Coloured Petri Nets*, Vol. 1, 2nd edn, Springer Verlag.

19. Kumar, S. (1995) Classification and Detection of Computer Intrusions, PhD thesis, Purdue University.

20. Levis, A. H. (1993) Colored Petri net model of command and control nodes, *in* C. Jones, ed., 'Toward a Science of Command, Control and Communications', Vol. 156 of *Progress in Astronautics and Aeronautics*, pp. 181–192.

21. Lindsay, P. A. (1997) Specification and validation of a network security policy model, Technical Report 97-05, Software Verification Research Centre, The University of Queensland.

22. Meta Software Corporation (1993) *Design/CPN Reference Manual for X-Windows*, version 2.0 edn.

23. Mitchell, M. (1996) *An Introduction to Genetic Algorithms*, Complex Adaptive Systems, MIT Press.

24. Neapolitan, R. E. (1990) *Probabilistic Reasoning in Expert Systems: Theory and Algorithms*, John Wiley and Sons.

25. Orchard, R. A. (1995) *FuzzyCLIPS, Version 6.04, User's Guide*, Knowledge Systems Laboratory, Institute for Information Technology, National Research Council Canada.

26. Richardson, G. P. & Pugh III, A. L. (1981) *Introduction to System Dynamics Modeling with DYNAMO*, Productivity Press.

27. Shannon, C. E. (1948) 'A mathematical theory of communication', *Bell System Technical Journal*.

28. Software Technology Branch (1997) *CLIPS Reference Manual, CLIPS Version 6.04*, Lyndon B. Johnson Space Center, NASA.

29. Staker, R. J. (1999) An application of Checkland's soft systems methodology to the development of a military information operations capability for the Australian Defence Force, Technical Report DSTO-TN-0183, DSTO, Electronics and Surveillance Research Laboratory, PO Box 1500, Salisbury, South Australia, 5108, Australia.

30. Staker, R. J. (1999) Information system network risk analysis using Bayesian belief networks, Technical Report DSTO-TR-0830, DSTO, Electronics and Surveillance Research Laboratory, PO Box 1500, Salisbury, South Australia, 5108, Australia.

31. Staker, R. J. (1999) Use of Bayesian belief networks in the analysis of information system network risk, *in* 'Proceedings of the 1999 Information, Decision and Control Conference, Adelaide', IEEE.

32. Toffoli, T. & Margolus, N. (1987) *Cellular Automata Machines*, MIT Press.

33. United States Department of Defense (1996) 'Report of the Defense Science Board task force on information warfare defense'.

34. van den Putte, B. & Hoogstraten, J. (1997) 'Applying structural equation modeling in the context of the theory of reasoned action: Some problems and solutions', *Structural Equation Modeling*.

35. Wagenhals, L. W. (1998) Executable models of influence nets using Design/CPN, *in* 'Proceedings of the 1998 Workshop on Practical Use of Coloured Petri Nets and Design/CPN', Department of Computer Science, University of Aarhus.

36. Waltz, E. (1998) *Information Warfare: Principles and Operations*, Artech House, Inc.

37. Wilson, B. (1992) *Systems: Concepts, Methodologies and Applications*, 2nd edn, John Wiley & Sons.

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19. ABSTRACT

This document describes a proposed program of research into theories, methodologies and techniques appropriate to achieving a systemic Military Information Operations capability for the Australian Defence Force. The major expected outcomes of this research are decision support aids relevant to Information Operations, contributions to the theory of Information Operations and contributions to IO Policy and Doctrine. The doctrine would include matters relating to the design of organisations that are capable of operating effectively in an Information Operations environment.