# Theoretical Foundations for Joint Systems Research

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**Abstract**

This paper proposes a theory of Joint Systems which is intended to be used to assist the Australian Defence Force to enhance its joint war-fighting capabilities. It should be noted that a theory that is suitable for treating Joint Systems, which are composed of human organisations supported by technology, may differ significantly from a typical physical theory in which the human element is absent. One conclusion arising from the theory is that a conventional systems engineering paradigm is unsuitable for addressing problems that arise in Joint Systems area. This is primarily the case because uncertainties due to human and organisational factors, as well as rapidly changing circumstances, make it impossible to establish the firm, fixed war-fighters' requirements on whose existence conventional systems engineering methods are predicated. As a consequence of the Revolution in Military Affairs, these uncertainties are radically increased in current times over those that have prevailed historically.

It is natural to ask whether there are existing methods which can be used to support Joint Systems research. One method that has recently gained prominence is the employment of architecture frameworks such as the C4ISR Architecture Framework to capture the details of Joint Systems in a uniform and consistent manner. However, when examined in the light of the theory developed in this paper, the C4ISR AF appears to have some deficiencies for supporting the *evaluation* of Joint Systems. In particular, it would appear that it fails to adequately capture and track the war-fighters' needs. Without an adequate up-to-date knowledge of these needs, it is impossible to evaluate how well a particular Joint System might fulfil them.

Some ways in which the C4ISR AF might be extended to better support the evaluation of Joint Systems are examined. Such extensions might also result in a tool that is better suited to supporting Joint Systems that operate in highly dynamic environments.

## 1. Introduction

Joint Systems Branch is a recently established branch of the Defence Science and Technology Organisation, Australia (DSTO). The purpose of the branch is to assist the Australian Defence Force (ADF) in enhancing its joint war-fighting capabilities, particularly through improved information exploitation and command and control support. Systems of Systems Group is a

* This paper summarises some research that has been performed by the author in pursuit of a postgraduate degree at the Systems Engineering and Evaluation Centre of the University of South Australia.

group within the branch whose main task is to evaluate the performance of Joint Systems by employing analysis, modelling and simulation techniques. The term “Joint System” is used here to mean a synthesis of personnel, doctrine and technical means drawn from several armed services, or perhaps from a coalition of forces, whose purpose is to achieve some aspect of military capability. Joint C4ISR systems are of particular interest, but other kinds of Joint System are also studied by the group.

Improved command and control and an improved ability to exploit information can be provided through the effective employment of C4ISR systems. However, the most effective use of such systems can only be accomplished when they are also accompanied by appropriate organisational, doctrinal and cultural change. The same remark is also true of other types of Joint System. Therefore, an analysis and evaluation framework that is suitable for Systems of Systems Group studies should be able to treat these humanistic factors in a way that is tightly integrated with the physical systems aspects.

If the Revolution in Military Affairs is to be succinctly characterised in any one way, it is by having brought about a discontinuous increase in the degree of uncertainty and rates of change associated with military matters. As a consequence, a framework that is suitable for supporting systems-of-systems studies in the present era must, additionally, be capable of coping with both uncertainty and rapid extensive change.

On the other hand, since Systems of Systems Group is primarily interested in examining broad issues concerning the interactions of systems, the inclusion of an excessive level of irrelevant detail that would impede a flexible investigation of the truly important issues should be avoided.

Significant attention has been paid in the past to architecture frameworks for distributed military information systems such as C4ISR systems. These provide a consistent approach for capturing system design solutions. However, it would appear that existing architecture frameworks give little consideration to the task of capturing the war-fighters’ needs that the systems are intended to satisfy. The elicitation and capture of the war-fighters’ needs is particularly an issue for systems that support joint war-fighting capabilities, where the possibly conflicting requirements of several independent organisations, which must function cooperatively and cohesively together, have to be reconciled.

Past work on architectural frameworks also appears to have given scant attention to the issue of how to effectively transform legacy systems into systems that can meet current and newly emerging requirements. The importance of tracking the evolution of needs as well as solutions, and of monitoring how well these are aligned, is heightened when both are evolving. However, a need for constant change is a direct consequence of the Revolution in Military Affairs. Therefore, in the author’s view, it is undesirable to separate the treatment of war-fighters’ needs from that of the solutions designed to satisfy those needs, particularly in the case of Joint Systems.

Consider, for example the C4ISR Architecture Framework proposed by the C4ISR Architecture Working Group [CAWG, 1997]. This considers three “views” of system architecture, “operational”, “system” and “technical”. For each of these views, it specifies a set of standard products that are intended to capture architectural details of a particular military operation. The details that are captured are those that are relevant to the design of C4ISR systems to support the operation.

The C4ISR Architecture Framework appears to follow a conventional systems engineering paradigm. Such a paradigm assumes that firm, fixed requirements can be identified at the outset and that it is simply a matter of developing a solution that meets these requirements and of capturing its details. The intent of conventional systems engineering is to tightly control the system development process so that the products which are delivered at its conclusion match what was originally thought to be required. If requirements change rapidly relative to the duration of the development process or the design life-time of the product, the result is inevitably doomed to failure. Conventional systems engineering is, therefore, firmly rooted in an earlier industrial age where change could be fairly strictly controlled. The conventional systems engineering approach is described in considerable depth by Blanchard and Fabrycky [Blanchard and Fabrycky, 1998].

Figure 1 is based on the "V"-model of conventional systems engineering ([Forsberg and Mooz, 1991], [Forsberg and Mooz, 1995]). It indicates where conventional systems engineering details for various levels of system integration would be captured in the C4ISR Architecture Framework "views". The three integration levels indicated would roughly correspond to the stand-alone system, network and enterprise levels. The dashed lines indicate the process of verifying that the solution matches the war-fighters' needs and functional requirements. This validation would normally be a part of the systems engineering process.

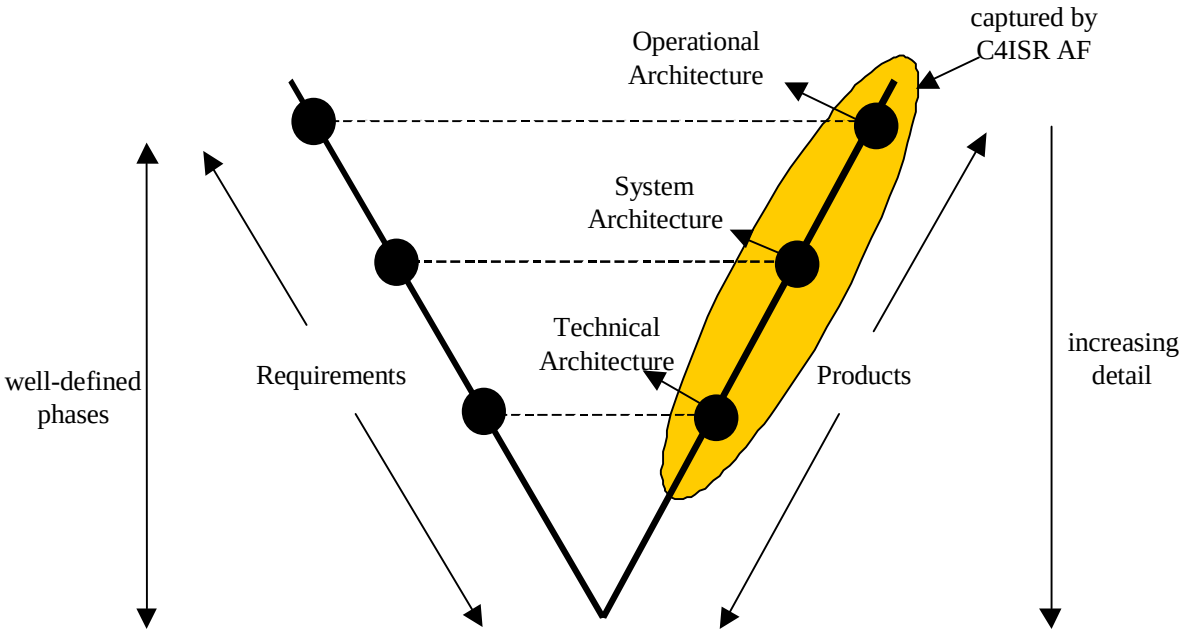


**Figure 1. Relationship between "V" model of Conventional Systems Engineering and the C4ISR Architectural Framework**

The C4ISR AF document referenced earlier defines an architecture description as "a representation, as of a current or future point in time, of a defined "domain" in terms of its component parts, what those parts do, how the parts relate to each other, and the rules and constraints under which the parts function". As illustrated by the figure, the C4ISR Architecture Framework captures many of the details of Joint Systems *solutions* in a structured form. However, it has evidently not been considered necessary to capture the relationship of the solution to the *war-fighters' needs*, as represented by the left half of the vee, to any significant level of detail or rigour. If such information is captured at all, it is only done so implicitly in a

simple unspecified narrative form in the “Doctrine, Goals and Vision” item of the “Overview and Summary Information” product (AV-1).

The fact that war-fighters’ requirements are not recorded in a detailed structured manner and linked to the solution elements which support them suggests an implicit assumption that they will not change during the course of the life of the system, an assumption that is typical of conventional systems engineering. The Joint Systems Theory proposed here challenges the assumption that the war-fighters’ requirements can be regarded as remaining fixed for the life of a Joint System. However, even in the case that these were static, it would not be possible to determine adequately how well they were satisfied by a particular solution from an examination of architecture framework products alone. This is a major reason for why the C4ISR AF cannot, without supplementation, be used as a basis for Joint Systems evaluations.

In summary, therefore, it may be concluded that the C4ISR AF appears to have several failings for the purposes for which Systems of Systems Group would like to employ such an architecture framework.

1. It omits detailed, rigorous capture of the war-fighters’ needs and consequently does not provide an adequate basis for Joint Systems evaluations.
2. It seems to implicitly assume that the war-fighters’ needs remain unchanged throughout the life of a Joint System, an assumption that is untenable in light of the Revolution in Military Affairs.
3. It does not tightly unite organisational, doctrinal and cultural issues with physical systems aspects. This is despite the fact that these may be critical for many Joint Systems.
4. A less significant objection is that it is intended to capture much detail that is not particularly relevant to the broader issues that Systems of Systems Group is interested in investigating. It would be better if some of this detail were collected in a more summarised form.

## 2. Joint Systems Theory

The main aim of this paper is to describe an embryonic theory which has been developed to provide a basis for redressing some of the perceived deficiencies of existing architectural frameworks. Here the term “theory” is used in the broad sense of meaning a system of ideas explaining something based on general principles, rather than in the narrow sense typified by physical theories. The principal tenets or propositions of this theory are that firm, fixed requirements are, in reality, often difficult to establish and that continually changing circumstances lead to a constant need for revision and amendment of Joint Systems. The impact of changing circumstances and the need for constant revision is also felt in related areas such as the acquisition and management of software intensive systems [STSC, 2000]. These features, and a revised version of the “V” model that accommodates them, are illustrated in Figure 2. The figure also indicates the parts of this revised model that appear to be captured by the C4ISR Architectural Framework.

A fundamental proposition of Joint Systems Theory, a consequence of the original propositions given earlier, is that the soft systems engineering model illustrated in Figure 2 is a more realistic model for the creation and evolution of Joint Systems than a conventional systems engineering model. This proposition has profound implications for what should be captured by an architecture framework that can adequately support Joint Systems.

The fluid forms of the sides of the vee in Figure 2 are intended to represent uncertainty in user needs and a corresponding uncertainty in solutions that may satisfy those needs. Figure 2 will be referred to as a soft systems engineering model because it explicitly recognises the existence of such uncertainties in the system development process. These uncertainties are due to human and organisational factors, as well as changing circumstances.

Given that such vagaries may exist in war-fighters' needs, it would appear to be appropriate to adopt fuzzy or probabilistic measures of the degree to which they are met by solutions. Candidate solutions which would result in the best fuzzy match to, or maximise the chance of successfully meeting, the war-fighters' needs would be favoured.

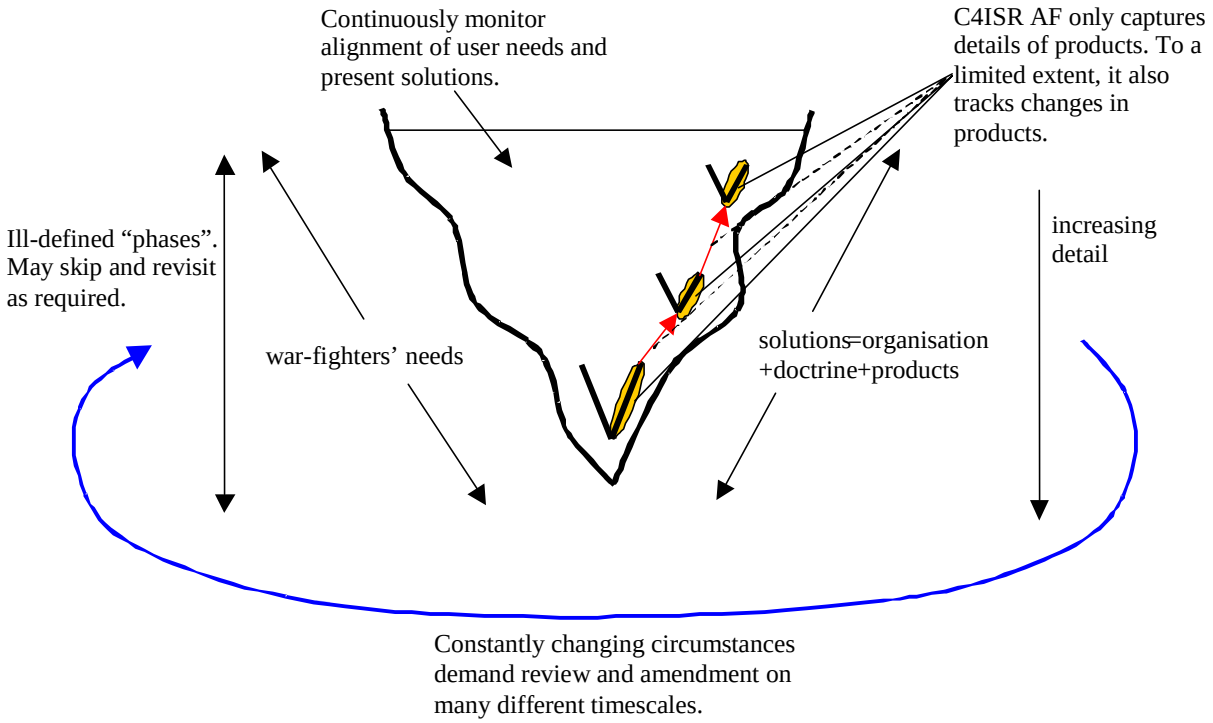


**Figure 2. Relationship between a Soft Systems Engineering Model and the C4ISR Architecture Framework.**

The soft systems engineering model presented in the figure incorporates conventional systems engineering as a subsidiary element, where it is appropriate to apply it. Episodes of use of conventional systems engineering are indicated by the straight-sided vees appearing in the figure. However, it should be clear that, where conventional systems engineering is employed, the duration of the formal development process must be kept short relative to the rate at which the war-fighters' needs are changing.

A corollary of the proposed Joint Systems Theory is that utmost caution must be adopted when considering undertaking the development of new products. Even if the requirements remain relatively unchanged during development, in a rapidly changing post-industrial world, it is quite likely that the products will become obsolete before their design life is achieved. In an era where technology is abundant, new development should be minimised by employing flexible off-the-shelf products to the greatest extent possible. Some similar comments are also made by Ferguson and DeRiso in relation to the acquisition of software-intensive systems [Ferguson and DeRiso, 1994].

The theory places great emphasis on eliciting and capturing the needs of the war-fighters as they evolve over time or the course of an operation. This emphasis is a consequence of the proposition of rapid change. “Soft” operations research methodologies are considered to be helpful for the purpose of eliciting and capturing war-fighters’ needs. It is obviously natural to employ methodologies that are based on general systems concepts, since the name “Joint System” itself implies that a systems metaphor is adopted. In the context of General Systems Theory, the concept of a “Human Activity System” has been employed to denote the result of using a system metaphor to describe the activity of collection of people interacting together to achieve some discernible purpose.

A number of approaches for dealing with complex Human Activity Systems have been developed in recent years. Descriptions of some of these, together with guidelines for choosing between them, are given by Flood and Jackson [Flood and Jackson, 1991]. Of these methods, one that appears to be particularly well suited to Joint Systems needs is Checkland’s Soft Systems Methodology (SSM). However, it will be necessary to extend SSM in various ways in order to achieve a viable methodology for Joint Systems research.

As an aside, some may doubt whether what is proposed here can reasonably be termed a theory. Rather than enter into a detailed discussion on this matter in this paper, the sceptic is referred to the thorough paper on organisational theory evaluation written by Bacharach [Bacharach, 1989]. While it is not claimed that this reference necessarily supports the contention that what is proposed here constitutes a theory, it certainly provides a sound framework for deciding the matter.

## 3. Soft Systems Methodology

Checkland’s Soft Systems Methodology (SSM), with appropriate extensions, potentially provides an appropriate method of investigation and treatment for Joint Systems. A feature of SSM that makes it attractive for investigations concerning joint capabilities is its ability to take account of the multiple viewpoints, and various perspectives within these, of the stakeholders affected in a situation.

It would be natural for these viewpoints to include those of the individual services involved in providing the joint capability under consideration. Another important feature is its focus on the transformation of an existing situation into an improved one. This means that it is well suited to dealing with a situation where legacy systems are already in place.

It is also appropriate for continuous improvement and evolutionary development strategies because it advocates iterative application of its investigation and treatment cycle, combined with reflection and learning from the results of previous applications of that cycle. Furthermore, a form of SSM might be embedded within the doctrine of an organisation to render the organisation more adaptive and capable of responding to changes in its environment.

However, SSM is not sufficient on its own to serve as the basis of a “scientific” theory of Joint Systems. Instead, its role within Joint Systems Theory is to serve as a bridge between the realm of scientific investigation and reasoning, and that of the human, organisational and societal issues of the real-world circumstances being treated. This is achieved by associating certain steps of SSM with scientific analysis and experimentation, as will be explained more fully later.

SSM relies heavily on the representation of those who may be affected by the outcomes in any investigation process. In its standard form, SSM provides some basic tools and techniques for

requirements acquisition and reconciliation which are useful when small groups of participants are involved.

SSM actually consists of two strands. These are “logical analysis” and “cultural analysis”. The “logical analysis” strand of Checkland’s methodology is composed of seven main steps. These are:

1. recognise a situation as being problematic and therefore requiring treatment;
2. describe the problem situation (using aids such as Checkland’s “rich pictures” for small groups of stakeholders, or perhaps more sophisticated electronic tools, as discussed later, for larger groups);
3. identify Human Activity Systems relevant to the problem situation, in the form of “Root Definitions”;
4. construct “Conceptual Models” of how the Human Activity Systems would ideally function;
5. compare the Conceptual Models with what is found in the real world;
6. from the results of the comparison, develop proposals for improvement which are feasible in the light of cultural analysis; and, finally,
7. take action to improve the problem situation based on these proposals.

In SSM, a “Rich Picture” is simply a collaboratively developed sketch or drawing depicting the features of the situation under investigation in way that is mutually comprehensible to those involved in conducting the investigation. However, it is not just any schematic or diagram as some might suppose. Its value lies in the collaborative process involved in its production, which is designed to foster a joint understanding among participants. This is an important point to observe in creating any electronic tool to replace Checkland’s original technique.

The Root Definition of a Human Activity System is composed of six elements. All may be explicitly contained in the Root Definition, or some may be left implicit if this would result in no misunderstanding. These elements are traditionally termed “Customers”, “Actors”, “Transformation”, “*Weltanschauung*”, “Owner” and “Environment”.

The “Customers” are those served or affected by the Human Activity System. The “Actors” are the people involved in performing the functions of the system. The “Transformation” essentially relates to the purpose that the system is perceived to fulfil. It is expressed as the change in the world that the system is perceived to bring about.

The term *Weltanschauung* is a German word borrowed from philosophy meaning “world-view”. This element is necessary because SSM considers that a system, being merely a metaphor, does not necessarily have an objective existence. For example, various observers may impute different purposes to a particular enterprise. A managing director might consider a company to be a system to supply him or her with the life-style to which he or she aspires, whereas shareholders might consider its purpose to be the maximisation of share value. Customers of the company would have yet another *Weltanschauung*. Thus, the one enterprise may be viewed as at least three different systems with three different purposes. The *Weltanschauung* element is needed to distinguish between these and thereby explicitly accommodate subjectivity.

The “Owner” element indicates who has the power to implement or veto recommendations that might be produced as the result of the SSM investigations. The “Environment” consists of the

restraining influences acting on the system. One such environmental constraint with which most would be familiar these days would be restricted funding. In this paper the term "environment" will be used to refer to the world outside a system, except in the context of discussing Root Definitions.

The Conceptual Models produced by SSM can be regarded as providing a high-level functional architecture, in that they enumerate the functions that should be performed by a system to achieve a stated purpose. They also record the contingencies that are presumed to exist between those functions. In traditional SSM, the collaboratively developed Conceptual Models are compared with what is found in the real world using a simple table and human judgment. A more elaborate example of using the methods of SSM together with electronic tools to create a functional architecture for a military system is given by Hunt *et al.* [Hunt *et al.*, 1999].

There would appear to be ample scope to replace Checkland's original methods with a more elaborate automated approach that could rapidly perform a comprehensive analysis to detect conflicts and ambiguities, and explore the effects of uncertainties that might exist. Some suggestions along these lines have already been made in the past. Hunt *et al.* employ a commercial enterprise modelling tool as an aid in refining and analysing their Conceptual Models. Boardman proposes a form of Conceptual Model that can automatically be translated into a Coloured Petri Model and which can then be further analysed using Petri Net theory [Sagoo and Boardman, 1998].

The cultural analysis strand of SSM is more interpretive. It centres on roles, norms and values. Roles have norms associated with them that govern the expected behaviour of people in those roles. Values are the measures by which the performance of people in their roles is judged. In addition, "political" power relationships are considered. These all evolve with time and changing external circumstances. An understanding of these aspects provides guidance on what interventions are likely to be cultural feasible at a given time. An electronic tool would merely provide support for recording the impressions of an analyst concerning these.

## 4. **The Virtual Enterprise**

It would appear that SSM has primarily been applied to monolithic or distributed enterprises in the past. The elements of such enterprises ultimately share a common owner. As the advanced world moves forward into a post-industrial age, there will be an increased need for methodologies that can deal with more tenuously organised enterprises. There do not seem to be any reasons why the principles of SSM cannot be equally well applied to such newly emerging forms of organisation. However, the original form of SSM described by Checkland and Scholes needs to be augmented in a standardised way to accommodate them conveniently [Checkland and Scholes, 1990].

One of these new forms of organisation is the virtual enterprise. There is a significant distinction between a distributed enterprise and a virtual enterprise. A distributed enterprise is geographically dispersed, but ownership is common and centralised. A virtual enterprise may or may not be geographically dispersed, however ownership is divided and shared between several entities. Also, the composition of a virtual enterprise tends to be relatively labile compared with traditional monolithic and distributed enterprises.

The Joint Systems Theory proposed here considers a military system to be analogous to a business enterprise. It is hypothesised that the virtual enterprise is a better analogy for a Joint

System than a monolithic or distributed enterprise. The analogy may not always be perfect, however.

## 5. Systems of Systems

Whether it is a Joint System or virtual enterprise that is concerned, it is hypothesised that an appropriate metaphor is that of a system-of-systems, that is, of a system whose components are themselves systems that are pursuing their own purposes and goals. While in monolithic and distributed enterprises the system components may interact in a number of ways, in a system-of-systems the component systems only interact through the exchange of information, or else indirectly through environmental effects.

For example, in a systems model of a distributed manufacturing enterprise, system components might interact through one component supplying another with partly finished goods. In a corresponding virtual enterprise, which is viewed as a system-of-systems, the supply will occur through the intermediary of a market, which is considered to constitute an element of the environment. A war-fighting example is delivery of military effects. These affect the war-fighting environment, but nothing is physically supplied to the beneficiary military systems.

In Joint Systems Theory, it is considered that the component systems of a system-of-systems can be monolithic systems, distributed systems or systems-of-systems themselves. Thus a hierarchy of systems-of-systems may be contained in a Joint Systems model.

## 6. Extending SSM for Joint Systems Research

As has already been noted, SSM requires some extension and augmentation before it is suitable for Joint Systems applications. SSM was evidently developed with business consulting applications in mind. A consequence has been that it is not particularly scientifically rigorous. Furthermore, the type of business for which it appears to have been developed seems to have been the more old-fashioned kind of monolithic enterprise that predominated in the nineteen eighties. Clearly the world has changed substantially since then, and the Australian military has been no exception.

One dramatic change has been the rapid and wide spread and acceptance of information technology. Most people performing managerial, scientific or technical work are now familiar and comfortable with this technology. Moreover, many have had exposure to using it to enable relatively convenient collaboration across large geographical distances.

As has been said previously, one of the features that often characterises a system-of-systems is that its component systems may be widely dispersed. This dispersion makes it inconvenient to apply Checkland's original methods which rely on physical meetings of study participants. Another problem with his original method is that it is highly reliant on the personal qualities of the staff facilitating its application. It would be desirable to be able to achieve consistently good results without confronting the necessity of finding facilitators with the requisite knowledge, skills and gifts.

There is an incentive, therefore, to find ways in which information technology can be used to replace Checkland's original methods. By using distributed software applications, participants could contribute to an investigation from the comfort of their normal work place, and at their own leisure. This would avoid travel and scheduling difficulties, as well as any unfortunate interpersonal dynamics that a physical meeting might encounter.

The employment of information technology in this way also permits the thorough and sophisticated analysis of complex Conceptual Models using a variety of analytical techniques and enables a more accurate assessment of how these compare with what is actually found in the real world. Another point is that many find SSM to be rather esoteric. By embedding its features in a software aid, they can be made immediately apparent to the user without the need for convoluted explanation.

SSM needs to be augmented to specify how it relates to systems-of-systems, which is the metaphor that it is desired to employ for Joint Systems research. To do this, Joint Systems Theory considers that the systems forming the components of a joint military system-of-systems are actually Human Activity Systems in the sense used by Checkland. Under this theory, a single military enterprise could conceivably be related to several different component systems in a military system-of-systems. The component systems would correspond to different Root Definitions derived for the same enterprise.

Also, a system-of-systems is, itself, regarded as a Human Activity System. Therefore a Root Definition and Conceptual Model should exist for the system-of-systems as a whole. Now there is a need to compare the Conceptual Model for the system-of-systems with the combined model that results from merging the Conceptual Models of the component systems and the information flows between them. What was originally a single stage process of comparing a Conceptual Model with the real world, now becomes a potentially many tiered process of comparing Conceptual Models with subordinate Conceptual Models until, ultimately, direct comparison with the real world can be accomplished. Consequently, the need for computer support for the process becomes more urgent.

### 6.1 *Elicitation and Capture of War-fighters' Needs*

For larger groups of participants than those originally envisioned by Checkland, more sophisticated tools and techniques than those traditionally employed may need to be used. Ideally these would be electronically-based and enable virtual teaming to take place, thereby avoiding the problems of arranging physical meetings between people who may be located in geographically dispersed areas and who have crowded schedules. This issue becomes particularly significant for systems-of-systems investigations, because systems-of-systems are often, by their very nature, widely geographically dispersed. Fortunately, there is a considerable body of work in the knowledge acquisition field that can be drawn upon here.

An overview of a number existing knowledge acquisition tools and techniques, together with some proposed extensions, is given by Bradshaw *et al.* [Bradshaw, *et al.*, 1993]. Another sophisticated set of tools is that developed by Shadbolt [Shadbolt, 1999]. Many of these tools make use of concepts from George Kelly's Personal Construct Psychology [Kelly, 1955].

One such concept that is frequently used is that of the Repertory Grid. This is a matrix with elements (that is, the items to be distinguished) usually listed down the vertical axis and constructs (that is, relevant distinguishing features) listed across the horizontal axis. Participants are asked to rate the elements against each of the constructs. The rating results form the contents of matrix. Constructs are so named because they are often determined initially from the participant's responses to a "triadic" elicitation technique developed by Kelly. However predetermined "constructs" are frequently used also. Constructs represent dichotomous perceptions such as "hot vs. cold" and "good vs. bad".

Traditionally, Repertory Grids use a numerical rating scale such as from 1 to 10 to indicate the degree of perceived agreement with one of the poles of the construct versus the other for a particular element. Here, the use of odds-based linguistic probability (or perhaps a better term would be plausibility) statements is proposed instead. This is done to allow the convenient use Bayesian Belief Networks in a later analysis stage. (Furthermore, it may be the case that such a rating scale is better attuned to the Australian psyche, which is renowned for its propensity towards gambling!) The odds-based Repertory Grids would automatically be converted to Bayesian Belief Networks that could be analysed numerically. This form of analysis would replace the standard statistical analysis methods traditionally employed for Repertory Grids. More information concerning Bayesian Belief Networks can be found in the book by Pearl [Pearl, 1988].

Another aid that some of these tools provide is a Concept Map editor. This serves a convenient graphical aid for eliciting problem domain ontologies. The word ontology is used here to mean the set of concepts, objects and the relationships between them in a problem domain. A Concept Map is a graph whose nodes are the concepts and objects in an ontology and whose arcs represent the relationships between those terms.

A problem with most of these tools is that they have not been created with the intention of distributed collaboration in mind. An exception is a tool developed by Gaines and Shaw which allows distributed collaboration by mean of a web browser [Gaines and Shaw, 1995]. This is achieved by constructing a distributed web interface to an existing knowledge acquisition application.

Recently, the Stanford Medical Informatics group has developed a new flexible knowledge acquisition tool which is written using the Java programming language and for which source code is available [Eriksson *et al.*]. This tool has been used to support some of the research described here. While very flexible, it lacks some of the more sophisticated knowledge acquisition aids, such as Concept Maps and Repertory Grids, as built-in features.

Nonetheless, it is possible to readily create at least primitive aids supporting such concepts using the standard “widgets”, or user interface components, supplied with it. In fact, for the purposes described here, this is a distinct advantage, since it permits the use an odds-based variant of the normal Repertory Grid. There is also the possibility of adding purpose designed “widgets” to the tool, written using Java, if desired.

Since the complete tool is written using Java, it can be deployed to geographically dispersed participants using standard web browsers. The whole tool would run on the user’s computer, rather than just the user interface, in contrast to the case of the tool developed by Shaw and Gaines.

### 6.2 *Scientific Aspects*

The nexus between SSM and the more scientifically-based aspects of Joint Systems Theory occurs in the areas of analytical modelling and scientific experimentation. Analysis and experimentation are, of course, both standard tools of the scientific method. The purpose of embedding them within SSM is to recognise that each has practical limitations on the fidelity with which it can represent the real-world situation. These limitations mean that there is a need to have some flexible and adaptive higher-order methodology that can be used to harmonise the scientific aspects of the investigation with the real-world problem situation. In addition, there

must be some standardised means for treating the human aspects of the problem situation that are not amenable to scientific investigation at all. SSM is used to fulfil both of these roles.

### 6.2.1 *Analytical Modelling*

The analytical modelling is performed, where appropriate, as a part of the fifth step of SSM, which is that of comparing the Conceptual Models with the real world problem situation. Architectural considerations become relevant in the process of translating the Conceptual Models into analytical models. The analytical models are constructed to reflect the relevant architectural requirements and constraints.

In the theory proposed here, analytical models will generally be built from a combination of Coloured Petri Nets ([Jensen, 1990]), to represent dynamic aspects, and Influence Diagrams ([Pearl, 1988]) to represent decision-theoretic aspects. Where knowledge has been captured in the form of odds-based Repertory Grids, it may be automatically translated into Bayesian Belief Network form. Since the knowledge contained in the Repertory Grids will have been gleaned from several participants, some form of reconciliation, such as that described by Rush and Wallace will be required [Rush and Wallace, 1997].

The analytical models are constructed using a combination of structured analysis and object-oriented design to manage model complexity. “Pattern languages” may be of assistance in constructing appropriate analytical models from libraries of pre-existing standard model fragments, thereby reducing the burden on the analyst and providing more uniform design solution proposals. The suggestions that have been made here are not intended to be proscriptive. The most appropriate analysis technique should be used.

### 6.2.2 *Experimentation*

Alberts *et al.* identify experiment as a key ingredient in facilitating the development of Joint Systems capabilities (which they refer to as Network Centric Warfare Mission Capability Packages) [Alberts *et al.*, 1999]. In the theory that has been developed here, scientific experimentation occurs as a part of the sixth activity of the SSM cycle, that of “developing proposals to improve the problem situation”. In the current context, there are two aspects to this step. The first is the introduction of organisational change to provide or improve a joint capability, which is achieved through improved doctrine and training. The second is the introduction of technical products in support of changes of the first kind.

The object of experimentation is to demonstrate that a proposed improvement has at least the potential to improve the problem situation, insofar as such a demonstration is possible under experimental conditions. Joint Systems Theory employs synthetic environments to the greatest extent possible in lieu of real world experimentation in order to reduce the costs and permit greater flexibility. This form of joint experimentation will be greatly facilitated in future by the recent establishment of a Military Systems Experimentation Branch within DSTO, which is a sister branch of Joint Systems Branch.

It is possible that a proposed “improvement” may prove to be less effective under actual conditions than it appeared to be under experimental conditions. Any such “failures” would be redressed as part of a subsequent iteration of the SSM cycle, if required.

## 7. **Knowledge-focused Architecture Framework**

The document describing the C4ISR AF states that it supports a product-focused approach, with aspirations towards supporting an information-focused approach in future [CAWG, 1997]. However, here it is proposed that a knowledge-focused approach may be more appropriate to support Joint Systems in the present era. A knowledge-focused architecture framework for Joint Systems would be designed to specifically capture joint war-fighter needs in addition to the aspects of Joint System design solutions already captured by existing architecture frameworks. In doing so, it would recognise the complexity and fluidity of post-industrial warfare by maintaining a basis for rapid revision, evolution and evaluation of Joint System solutions. It would also provide a traceable historical record of needs and solutions from which longer-term lessons could be drawn.

This would be achieved through employing Checkland's Soft Systems Methodology as the foundation for the overall architecture framework. The augmented systems-of-systems form of SSM described earlier would be used. The joint war-fighters' needs would be recorded, at their most abstract level, in the form of Soft System Methodology concepts such as Rich Pictures, Root Definitions and Conceptual Models in a knowledge repository. This basic outline would be further enriched with problem domain specific Concept Maps and war-fighters' opinions and preferences collected using Personal Construct Psychology concepts such as Repertory Grids.

At this point, detailed analytical models could be constructed and compared with the real world situation as outlined earlier. Intervention proposals derived from the comparison would be linked back to the needs that they were intended to satisfy, thus automatically providing both traceable requirements and a means for deriving appropriate measures of effectiveness. The results of intervention proposals that are implemented would be recorded using framework products similar to those contained in existing architecture frameworks. However, increased attention would be paid to recording design solution increments and to linking these and the original solutions back to the interventions from which they result. There would also be increased emphasis on recording organisational, doctrinal and cultural aspects.

The DSTO Experimental C3I Technology Environment (EXC3ITE) provides a distributed computing environment within which DSTO researchers can demonstrate future technologies and concepts. It may be appropriate therefore to include the basis for a knowledge-focused architecture repository within EXC3ITE in the form of a knowledge base server and appropriate basic ontological framework.

## 8. **Conclusion**

This paper has a proposed an embryonic theory of Joint Systems that recognises that such systems will inevitably be subject to much uncertainty and change due to the turbulent nature of current times. A conclusion that is reached is that it is of paramount importance to focus on eliciting and capturing the changing needs of the war-fighters and linking these to the solution elements that support them. The theory predicts that methods that do not provide explicit support for these changing needs will not be successful in providing effective Joint Systems support. Consequently, an extended, knowledge-focused architecture framework has been outlined that would be more theoretically appropriate than existing architecture frameworks for supporting Joint Systems in the current post-industrial age.

This extended architecture framework focuses particularly on capturing war-fighter opinions, needs and preferences and relating these to the solutions designed to satisfy them. This means that the knowledge required to rapidly refine and adapt solutions to changing circumstances and unanticipated outcomes is captured within the extended architecture framework in a form which can easily be updated and used for subsequent design revisions. It has been suggested that facilities be added to the DSTO Experimental C3I Technology Environment to support such a knowledge-focused architecture framework.

It is anticipated that a knowledge-focused architecture framework, in combination with appropriate knowledge acquisition, analysis, modelling, simulation and experimentation tools and methods will provide a practical means for achieving effective and systemic joint capabilities for the ADF for the future.

## 9. **References**


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