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Socio-Technical Systems

- Practical OR in the face of the human variable

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Introduction

This paper is based on a presentation given at the 20th International Symposium on Military Operational Research (held at Eynsham Hall, Oxford, August 2003) combined with reflections on the presentations and discussions from the Human Decision Making in Complex Systems conference (held at Dunblane Hydro, Scotland, September 2003). The paper explores the need for Operational Research (OR) studies to embrace the variability arising from human participation in the operations and systems studied, and the consequent need for the human science communities to develop and present knowledge in forms which are amenable to exploitation by OR practitioners. Although the paper is principally concerned with the exploitation of human sciences by OR, it becomes clear that significant cross-disciplinary exploitation within the human sciences will be a pre-requisite for satisfying OR's needs. The paper is, therefore, a call to action for both communities.

The nature of OR

OR, is concerned with the analysis of interventions with the operations of systems or organisations of interest to executive decision-makers, who are the OR customer. Since OR tackles real world problems of interest to human executives, and since the systems involved are usually embedded in human organisations, it can fairly be asserted that OR is principally concerned with the analysis of socio-technical systems. *(footnote: for the rest of this paper the terms 'system' and 'system of interest' will be assumed to refer to socio-technical systems)*

Consequently, it is important for OR methods to be able to deal with socio-technical factors and issues. This raises several challenges for OR methods which have not, to date, received enough attention in the practitioner community, but in the face of which practical steps can be taken to improve the state of practice.

Challenges for OR

The key challenges for OR can be categorised into the problems of modelling, data, prediction and intervention.

The problem of modelling

All good OR studies begin with a problem formulation stage involving the construction of a conceptual model of the system of interest (reference NATO

COBP). This model captures the joint understanding of the analysts and their client about the system (as well as clarifying the intervention decisions the client wishes to make concerning that system). The problem model also serves as a common description between the analyst and those who provide scientific and domain expert knowledge to the analysis, and is a key factor in selecting the analysis method to be used.

It is critical, therefore,that the problem model be as complete as possible and that it faithfully represent the real world factors, structures, processes and effects that impinge on the study problem. All OR practitioners should be multi-disciplinary in outlook, but a small study team cannot hope to have detailed knowledge of all of the disciplines required to construct the problem model. They must, therefore, rely upon knowledge provided by specialists. It is critical that such knowledge be trustworthy and that it is communicated in such a way that the OR practitioner can understand and use it.

This problem implies a challenge to the providers of specialist knowledge to ensure that their conceptual models and theories are adequately comprehensive, comprehensible and trustworthy, especially when set against the conceptual models of other specialists whose knowledge must be synthesised with theirs to produce the OR problem model.

For example, consider an OR study in which the client is considering implementing some new networked information systems (IS) to support transformation of its business to face new challenges in the market-place. The system of interest is socio-technical, involving the IS, the business processes, organisation and culture, and the market place in which the business participates. All of these facets of the system may be affected by the implementation of the new IS, and so all are part of problem and need to be included in the problem model.

To achieve this, knowledge will be required from a range of disciplines, including: Information technology, systems engineering, organisational psychology, management science, economics, cognitive psychology, teamworking, etc.

The problem of data

OR studies the operation of systems and this critically depends on having data describing and evaluating that operation. Initial data are required to fully construct a requisite problem model. These are data about the current operation of the system and its structures and processes. Such data are not easyto acquire,particularlyifthe system of interest is not in continuous operations (like a productionline) but only called into action on a contiingency basis (like a military capability). In the latter case even the constituents of the system may be unclear before the preparation for the contingency occur. In this context the OR practitioner needs to assemble either generic variable data or data on the potential distribution of key variables in the problem model. The goal of data generation for OR is to develop from the conceptual problem model into a generative model which can support inference about the system of interest.

Typically, data are in short supply and are less accurate, precise or reliable than would be ideal. However, themethods of OR have evolved to deal with such data while still producing useful insights and advice for the executive decision-maker. Thus data need only be good enough to allow the OR practitioner to improve upon the executive's intuitive understanding of the system. If this is not possible, then OR should retire from the scene and be replaced by facilitative decision support (or nothing at all!)

The challenge, in relation to human and organisational data is to be able to cast the existing scientific knowledge base into a form which can be used for problem modelling and inference. This requires relevant scientific disciplines to clearly delineate the key variables of the system, their likely values (or distributions) and the nature of the relationships between them. OR methods can make use of logical, descriptive or numerical data, although numerical is preferred for a variety of reasons.

As with modelling, the reliability of data is paramount and this implies coherence across the domains of expertise providing it.

The problem of prediction

OR is founded on an essentially rationalist philosophy. It makes the presumption that the system of interest to the executive can be analysed and that this analysis will produce insights which the executive can use to intervene in the system in order to produce desired effects. This, in turn, presumes some measure of predictabiity either in the system behaviour under intervention or in some more abstract properties which will influence future system behaviour. The quality of the conceptual problem model is the key to success of OR studies. However, even with a good conceptual model and adequate data to understand it is no guarantee of predictability. The fact remains that socio-technical systems tend to be complex adaptive systems (CAS) as defined by Peter Allen (reference Allen). In such systems there is a fundamental problem with forecasting the dynamic macro-behaviour of the system, even with complete knowledge of its variables and relationships. CAS may exhibit remarkably simple and stable macro bahaviours despite micro-level complexity and variability, or they may produce complex macro behaviour from simple micro behaviours. CAS may also flip without warning into totally different modes of behaviour in response to apparently insignificant changes or even with no apparent change at all. In the worst case CAS may become chaotic, responding so sensitiviely to minute variations in the detail that the macro behviour appears effectively random. While it may be possible, theoretically, to accurately predict such systems, given full enough knolwedge of them, it is often be the case that the model needed to make the prediction reliably has to be as detailed as the real system and not able to deliver its 'prediction' faster than the system itself evolves.

This difficulty has led many analysts to declare that prediction is not possible in CAS and that OR should not attempt it. However, drawing inferences about the consequences of executive intervention in a system doesnot require precise forecasting of system future behaviour. Executive are prepared to take risks an

may only need a description of general trends, or a statistical prediction as in, for example, a typical weather report. When the weather forecaster tells you that there is a 40% chance of rain somewhere in your region, what he is really doing is providing you with the information to make a risky choice between taking your umbrella out (with consequent effort and inconvenience) or not (with a riskof getting wet). Similarly, when an OR study advises that a proposed intervention will more likely succeed than fail, it is giving the executive information to take a better gamble - it is, so to speak, "loading the dice" in favour of success.
Other dimensions fo predictability may also be exploited. Mintzberg (reference 1979) identifies relationships between organisational structure and task environment. This knowledge can be used as a generic model to give useful insights about the likely response of an organisation to a forced change of structure or environment.
Executives need evidence which will add value to their intuitive prediction capabilities. It is no good just given them historical data and ducking the question of its utility for predicition. Indeed, any knowledge about a system of interest given to an executive will inevitably be used predictively, even if the extent of the prediction is only that the knowledge provided will remain valid during and after the proposed intervention.
Thus, the idea of prediction should not be discounted as impossible and not worthy of consideration in socio-technical systems. Rather, all concerned must strive to generate maximum clarity over which insights can reasonably be used to predict or shape the future, and only such insights should be offered to OR practitioners or executives.

The problem of intervention

The final challenge for OR, and the providers of its underpinning domain knolwedge, is the fact that socio-technical systems are all, to a greater or lesser extent, self-aware and liable to be aware of and reflexive to any interventions perptrated upon them. Self-awareness adds an extra dimension to a system's response to intervention. Individual and collective decision-making becomes a critical feature of CARS. The self aware system can generate behaviour which either reinforces or undermines the executive's intentions. The human sciences have a key role to play in providing OR practitioners with the knowledge needed to take account of such reflexive behaviours and the subsidiary interventions needed to control or mitigate them as required. OR practitioners, for their part, need to understand the possibilities for reflexive response, on top of the other challenges, and to think of executive intervention as multi-cycle process, with interactions between intentioned and motivated actors, rather than an event with consequences. An essential element of the understanding required by OR practitioners is a clear concept of what a socio-technical system is and what it implies.

What is a socio-technical system?

Different definitions of socio-technical systems exist in the literature exposing some subtle distinctions (ref?) but for the purposes of this paper only a very basic distinction needs to be made between technical, social and socio-technical systems.

A system can be defined as an interacting collection of parts. If all of the parts of a system are non-human technologies then one has a purely technical system, for example an autonomous robot or an unmanned production facility.

A social system is an interacting collection of humans in which non-human technologies are either not present or not significant to the operations of the system. A community of people doing something like talking for which technology is not really an issue might be considered a purely social system although, in modern societies, such technology-free activity is rare.

By extension of the above definitions, a socio-technical system is an interacting collection of human and non-human parts. However, for the purposes of this paper a further condition is imposed. To be chracterised as socio-technical it is not enough simply be a technical system with human users who interact rarely and in a relatively 'stand-off' way. To be truly socio-technical the human and technical components must be integral to the system and overall system behaviourmust arise from multiple cycles of interaction with and between the humanand non-human parts.

The assertion that all systems of interest are socio-technical is especially relevant to military OR (also known as operational analysis, OA). This is because military conflict is an essentially human affair but one in which technology plays a deeply significant role. Technology is so important to modern military affairs that is has been tempting for OA practitioners to consider the technical component alone. This is particularly so with the increasing use of automation, 'smart' munitions, and unmanned vehicles. However, as General Rupert Smith once commented (ref FRN presentation) "Unmanned warfare is pointless"; the human element cannot be ignored.

On the other hand, is can be tempting to fixate on the human component of conflict to the exclusion of all else. This is equally misguided and likely to lead to poor advice to the executive.

The human component in systems of interest to OR can be seen as a constant source of variability and change, which produces challenges to systematic analysis. Indeed, whilst much about the impact of humans on systems is difficult to predict or understand, the one dependable fact is that humans bring variability to socio-technhical systems - they are, so to speak, the constant variable.

Humans - the constant variable

Change is one of the defining characteristics of life. Any system with humans involved will change and adapt. Variability is a feature of humans, both individually and collectively. Research clearly shows that there is significant variability between individuals and groups and also within individuals and groups over time. Understanding these sources of variability is key to allowing OR to include humans in its methods and models. This paper will, therefore, spend sometime cataloguing and discussing the nature and sources of human variability.

Individual human variability

Humans differ from each other in ways which affect how they behave inside socio-technical systems and how they perform tasks in those systems. Individual humans also change over time as a consequence of learning and experience, or in response to changing context and environment. In order for OR practitioners to understand and deal with individual human variability they need to understand the forms it takes and how it arises.

Variation between-individuals

Given exactly the same situation, under exactly the same conditions, two typical people will react and behave differently. How differently depends on many things.

For example, imagine that you are reading this paper seated on a park bench when a man in soldier's field uniform carrying a rifle come up and stands in front of you. How will you react? What will you make of the situation? What will you 'see' standing there in front of you? One person may see a strong protector of freedom and security, and perhaps wonder if there is a threat nearby, a terrorist bomb or a riot. Another person will see the soldier himself as a threat, a menacing representative of repression andinjustice. Yet another may see a young, immature fool, suckered into a dangerous profession by propaganda and the promise of a trade. Each of these views could legitimately be held by a citizen of the UK. It all depends on their past experiences with soldiers. A resident of certain streets in Belfast will see the soldier quite differently from the landlord of a public house near the army barracks in Bordon, and a quite different view again may come from a gauche young proto-marxist from north London.

Such different perceptions arise from a host of sources - memories of past experiences, cultural norms instilled since childhood, self perceptions and the way a person 'spins' their position in relation to the world, even deeper factors like personality or the current state of arousal and anxiety.

Recent experimental work (reference Mathieson and Malish 2003) has shown the potential for personality to significant effect on how military commanders choose to act in a variety of situations.

Work by Sicard et al (ref Paper 14) suggest the intriguing possibility that risk taking may be related to a need to regulate risk propensity levels.

At a more basic level, what each person 'sees' is the result of a complex cycle of perception, attention, and recognition involving the imposition of previously formed categorisations or symbolisations onto the 'sensory wash' and the construction, from remembered fragments, of a story to “explain” the juxta-position of those symbolic representations. Indeed the need to 'make sense' of the world in this way may even result in the construction of quite fictitious explanations and the neglect of countervailing perceptions in order to preserve the current 'mental model'. This is graphicallyillustrated by the illusion at figure (FIGURE OF ELEPHANT) which works because of our minds insistance on seeing

an elephant despite the cognitive problems that belief entails.
This combination of history, culture, politics, psychology and physiology provides many ways for people to differ, and the interaction of the different causes can make it difficult to provide any clear pattern or distribution from which to generalise. Some clues might be had from past observations, or from profiling of various sorts. If one is interested in advising soliders on how to conduct themselves in the course of peace-keeping operations it may be vital to understand what knolwedge is relevant to the analysis, and which disciplines should be included in the OR team.

Conclusions from recent experimental research *(involving both Navy and Army commanders)*

- Personality has a significant effect on what course of action a commander chooses
- It is at least as important a factor as information changes equivalent to implementing current Digitization plans

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Within-individual

variability.

- two brains/ two minds
- multiple goals/ standards
- emotional reasoning
- awareness and learning

Emotional reasoning

- The human brain processes sensory stimuli using multiple pathways to the frontal cortex
- For example, signals from the eyes to the frontal lobes also pass through the emotional centres
- Evidence from brain-damaged patients suggests that reasoning processes depend upon this parallel emotional process working properly
- Hence, any decision theory which is based on rational treatment of utility must be treated with scepticism

Collective human variability

Within-group

variability.

- Social networking/ association/ competition
- Interaction between structure and mechanisms
- Self awareness and reflex
- Self-organisation/ emergent change

Between-group

variability.

- Culture
- Formal goals, structures, empowerment
- History and collective experiences

Interaction of structure/mechanism

- **Unusual 'skills fade'** - based on a true story
- In a recent exercise, the proportion of soldiers skilled in using a new piece of kit went down during the event.

Unusual 'skills fade' - based on a true story

- Those that were skilled in the new system were more frequently called in to fix it.
- After a few broken nights, some had 'chosen' to become 'unskilled' so as to shift the demand elsewhere!
- Organisation capabilities depend on participation, which is often variable in response to processes.

Self awareness and reflex

- Radical change in attitudes within the USA before and after '911', apparently quite disproportionate to any rational assessment of the global threat
- Contrast this with the almost negligible change in attitudes before and after natural disasters in the USA
- This variability in reflexive change seems to depend upon deeply human characteristics, including collective self image and attitudes towards group membership

Culture

Human science researchers

- Most important part of a report is the references
- Standard for valid evidence is 95% confidence
- Less significant data is useless without further further research

OR practitioners

- Most important part of a report is the conclusions
- Standard for valid evidence is anything better than 50:50 odds
- Success is 'loading a decision -maker's dice'

History and collective experience

What do you see?

Practical OR responses

- Balanced problem formulation
- Making "natural" behaviour the norm for modelling, rather than assuming a rational norm with human modifiers
- Multi-theoretic, multi-method OR
- Treating uncertainty rather than suppressing it
- The need for synthesis to bring analysis back to reality
- Implications for multi-disciplinary OR teams

Balanced problem formulation

- "The problem is not formulated until the assessment team has addressed each

aspect of the problem."
- "Practical constraints such as data availability, study resources and limitation of tools should be treated as modifiers of the problem formulation [not] initial drivers."
- "In dealing with fuzzy or uncertain boundaries, the problem formulation process needs to explore and understand the significance of each boundary before making assumptions about it."

(NATO Code of Best Practice for C2 Assessment, 2002)

Modelling the 'natural core'

Pre-1980's
- Rational model of model of human decision making
- Decision theory base
- Focus on utility and cost
- Optimised choice from options
- Largely open-loop process

Post-1980's
- Bounded rationality model
- Natural decision maker model
- Cognitive science base
- Focus on experience/expertise
- Single satisfactory action
- Tightly cyclic closed-loop

Modelling the 'natural core'

Formal organisation
- Purposive and task oriented
- Coherent goals
- Established structures
- Determined roles and rule
- Shared culture
- Coherent commitment
- Stable over time

'Natural' organisation (?)
- Social network oriented
- Multiplicity of unshared goals
- Ad hoc structures
- Emergent roles and rules
- Multiple cultures
- Varied commitment
- Adaptive over time

Example: Adaptive process in C2IS

Example: ModSAF

- ModSAF model has been modified to include the effects of known human variables on participation - not just keeping your head down but also effects of team cohesion, shock and surprise (making ShockSAF)
- Representation not perfect but makes a big difference to outputs

Example: Existing research results

- Research on modelling human decision making reported in 1999:
  - identified practical algorithmic ways to represent a wide variety of HDM phenomena depending on the type of base model
  - provides a simple expert system to aid assessment of issues
- Research on human contribution to command effectiveness reported in 2001-2003:
  - experimentally determined relative importance of information, personality, and experience to command behaviour
  - identified personal constructs used by commanders to recognise and assess situations

Short term possibilities

- Perception: Add a two stage process in the chain from sensor picture to action generation, allowing 'picture' to be transformed before decision-making takes place
- Decision making: Provide less precise optimisation of options, but allow variable choice of a satisfactory CoA
- Personality, experience, etc: Include variables in models with impact on CoA selection and, in the absence of harder data use these for sensitivity analysis
- Multiple goals: Implement explicit goals in different sub-units, including local and personal goals with explicit mechanisms for goal promulgation

Longer term possibilities

- Decision making: Modify DM algorithms to trigger from more abstract, task specific constructs that are the basis of bounded rationality. Then generate those constructs in the perception algorithm (mentioned previously)
- Organisation structure: Introduce mechanisms to allow social networking to influence how structure affects information flow and process implementation
- Adaptation: Implement more comprehensive representation of adaptation in people, process, structure and capability to allow modelling of reflexive behaviour

Multi-theoretic, multi-method OR

- Dealing with socio-technical issues will challenge existing OR capabilities
- Immediate response should be to use multiple methods, possibly even multiple theoretical bases, to address issues raised by problem formulation
- Longer term response must be to seek synthesis of theories so that multiple methods become compatible *(ref Knots, Lace and Tartan to be presented at OR45)*
- Risk-based methods as well as effectiveness-based

Treating uncertainty

Synthesis

This between individuals variability means that OR practitioners need to accept and deal with an inherent uncertainty over the behaviour and performance of human elements of future system or systems in which the humans rotate through roles and jobs. Such uncertainty is not problematic for OR methods provided some estimate of its scope and scale can be made. Treatment of uncertainty and other methods for handling between-individuals variability are dealt with later in this paper.

- Synthesis is often the unregarded twin of analysis
- Even those human and organisational issues which have to be excluded from the analysis through lack of capability can be re-introduced during synthesis (provided they were explicitly identified at the start)
- "Problem formulation must not only provide problem segments amenable to analysis, but also a clear and valid mechanism for meaningful synthesis to provide coherent knowledge about the original, larger problem"
  (NATO Code of Best Practice for C2 Assessment, 2002)

Multi-disciplinary OR teams

- "The assessment team must be interdisciplinary." (NATO Code of Best Practice for C2 Assessment, 2002)
- Operations Research involves the study of real systems.
- All real systems of interest are socio-technical in nature.
- Hence, OR requires the exploitation and synthesis of knowledge from multiple (scientific) disciplines, such as:
  - physics, physiology, cognitive psychology, mathematics, utility theory, information science, systems theory, teamworking, group decision-making, collective behaviour, organisational theory, organisation psychology, management science, complexity theory, politics, economics, social science, culture, anthropology, religion, philosophy, ……

Summary of human science issues

- Individual human sciences have evolved in the last 20 years - be aware your understanding may be dated
- Teamworking and team behaviour are well researched, although predictive models of performance are limited
- Human organisations (even professional, task-oriented ones) are deeply social entities
- Social factors are significant variables for military capability

Summary

- All systems of interest to military OR are socio-technical in nature and the validity ('fitness for purpose') of OR depends upon a balanced treatment of factors
- Human science needs as much respect as other sciences, it is dangerous to take a layman's approach
- The wide range of humans sciences is not integrated and expertise is required to treat human issues well
- Having a token human scientist on the team is not enough - good problem formulation should identify needs
- Treatment of socio-technical systems is not too difficult and there is no excuse for OR not dealing with them