CRANFIELD UNIVERSITY

Lorraine Dodd

Choose-ables, Sensing and Sense-making: A study of Orders of Choice

CRANFIELD SCHOOL OF DEFENCE AND SECURITY

PhD by Published Works

Academic Year: 2019-20

Supervisor: Dr Ruth Massie

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ABSTRACT

There has long been academic study into decision-making to look at different strategies that are used to select a course of action from a set of decision options. The subjects making these decisions, the decision-agents, tend to be objectively rational with selections made based on maximising expected utility or minimising probability of loss. There is, however, a lack of research into how the options for choice are settled upon in the first place. It is this topic of choice-making that is the focus for this research study, which covers the subjective nature of choices being 'imagined deemed possible' in the form of 'choose-ables' as related to what that subject might be sensing and understanding. Choose-ables are a subject's options for choice, given the nature of their sense of context and their felt conditions. In this respect, choose-ables are subjective and relative respectively. The main proposition is that any subject has an associated range and scope of choose-ables, and that these can be organised according to the nature of the choose-ables open to that subject.

The research gap being addressed by this PhD study exists due to the lack of a formal theoretical framework to examine why and how a subject's options for choice are settled upon by that subject. Therefore, the contribution made by this PhD by Published Works is an order of choice framework that has a two-fold application: first, the explanation of what might shape the nature and scope of a subject's choose-ables; second, a way of formally appreciating and analysing the implications of those choose-ables for a subject's sensing and sense-making; hence, potentially for 'modelling' the forming of their subjective potential for choice-making and any emergent behaviours.

This thesis presents a seven-fold framework for orders of choice, applicable to a range of subjects; from agent-based algorithms and cells through to people, organisations and political institutions. A key assumption is that each subject makes choices according to a principle of discomfort avoidance. Subjective preferences, interests and needs relate to a subject's scoping of their choose-ables, according to a subject's sensing and sense-making of their circumstances. Preservation of a subject's sense of comfort acts as a central concept of subjective 'settling', which governs the nature of the choose-ables according to where any subject is in relation to their context. The overarching research question is: *From where might a subject's choose-ables emerge; and how might these choose-ables moderate, or be moderated by, that subject's sense-making and their focus of attention?*

The portfolio of seven published works covers the supporting theories and also describes the background experimental work that prompted the development of the linking of the two underlying theories: Catastrophe Theory and Cultural Theory. This thesis formalises the links between these two theories and Shackle's (1976) work on choose-ables. The orders of choice are aligned and associated with other levels of capability, organisation, and adaptation; then developed into a nested framework based on Catastrophe models with further understanding drawn from other, related, theories about levels of capability and organisation, drawing on relational frameworks in Cultural Theory. The framework contributes to knowledge by providing a formal mathematical basis for a descriptive language that can be applied in order to understand and appreciate where any subject might be in terms of their choose-ables, their sensing and their sense-making, and to help to explain why. A significant conclusion is the centrality of a subject's concept of value for their choice-making.

PORTFOLIO OF PUBLISHED WORKS

Presented below is a list of citations for the seven publications; followed by a short precis for each paper (in narrative order, not in date order):

1. Dodd L, Moffat J, Smith JQ, and Mathieson G (2004) Discontinuity in decision-making when objectives conflict: a military command decision case study. 21st *International Symposium on Military Operational Research*, UK. http://ismor.cds.cranfield.ac.uk/21st-symposium-2004 (see also: Dodd L, Moffat J, Mathieson G and Smith JQ (2003) From simple prescriptive to complex descriptive models: an example from a recent command decision-making experiment. *Proc. 8th International Command & Control Research & Technology Symposium*, National Defense University, Washington.)
2. Dodd L and Smith J Q (2012) Devolving command decisions in complex operations. *Journal of the Operational Research Society*, 64:1, DOI: 10.1057/jors.2012.7
3. Dodd L (2011) A Theory of Choices: melding black swans, butterflies and swallowtails, *Proceedings of 8th International Conference on Complexity Science*, June, Boston, USA.
4. Dodd L and Markham G (2013) Orders of C2 agility and implications for information and decision-making, *International Command and Control Research Technology Symposium*, Institute of Defense Analysis. CCRP Publications. https://apps.dtic.mil/dtic/tr/fulltext/u2/a587016.pdf
5. Dodd L and Alston A J (2009) Complex Adaptive and 'Inquiring' Systems Theory for Contemporary Military Operations: A Multi-perspective Approach, *The Cornwallis Group XIV: Analysis of Societal Conflict and Counter-insurgency*, Vienna. http://www.ismor.com/cornwallis/workshop_2009.shtml
6. Dodd L (2018a) Techne and techniques for engaging in a socially complex world, *Journal of the Operational Research Society*, 70:9, DOI: 10.1080/01605682.2018.1501461
7. Dodd L (2018b) Choice-making and choose-ables: making decision agents more human and choosy. *Euro Journal on Decision Processes*, Volume 7, Issue 1–2, pp. 101–115 https://doi.org/10.1007/s40070-018-0092-5

Abstracts drawn from the publications

Publication 1

Dodd et al (2004) explore the applicability of the agent-based decision theory using the results of a command decision-making experiment to verify the basis for the theory. The experimental results show that splitting-factors can be derived from the subjective nature of the situation assessment, and these seem to be moderated by the subject's preferences, training, experience and personal history. The paper recommends that in order to capture these deeper aspects of the human decision-making process, there is a need to visualise a choice landscape whose contours are defined by the subjective evaluation of the 'potential losses' of moving over the landscape. These choice landscapes are wholly subjective and they change as the decision-maker's 'world' changes over time. The experimental results of this study illustrate these points, showing that the move towards more complex, less prescriptive agent-based models increases the need for more subjective understanding.

Publication 2

Dodd and Smith (2012) presents the first stage in the development of the application of Catastrophe Theory models to decision-making in complex operations. It uses the mathematics of the cusp catastrophe, based on maximising the likelihood of conflicting utilities. A key point of reference is the inter-relationship between a subject's preferred course of action and their focus of attention; in particular, if there is doubt or uncertainty in situational information then it could easily be ignored, especially if it adds to (or further confuses) the degree of internal contention being felt. The theory is developed to show that the geometrical forms of expected utilities, which arise from the assumption of commander rationality[1], are qualitatively stable in a wide range of scenarios. This expected utility theory opens out into further analysis linking to Catastrophe Theory as it relates to regulatory frameworks for devolving command decision freedoms for choice. Publication 2 shows how an appreciation of this form of geometry can aid understanding of the relationship between socially-complex operational environments and the prevailing choices open to commanders.

Publication 3

Dodd (2011) moves towards a formal mathematical foundation for developing orders of choice relating to focus of attention, interpretations of a changing situation, and adaptation. The theory provides insight and supports reasoning about the challenges brought about by differences in ways of sensing, observing, noticing, interpreting, modelling, assessing, adapting and responding. This paper is the first introduction to the four Catastrophe models: the fold, cusp, swallowtail and butterfly, as described by four parameters, representing four different natures of choice: normative response; approach to variability and uncertainty; ways of projecting forward; and open-ness to values. The theory makes the assumption that choices are made and decisions are taken according to a principle of viability or sustainability such that any subject is striving, where possible, to preserve such a principle, according to whatever is the subject's scope of interest, need and concern.

Publication 4

Dodd and Markham (2013) define four orders of agility and examine the concept of value, leading to an ordered model of nested choice-making. A model of four orders of agility provides a unifying scheme, which gives greater confidence that different conceptions of value and assessment measures can be organised systematically. This nested representation of orders of agility becomes a useful source of rigour. The paper discusses organisational constructs that reflect on the dimensions of organisational behaviour (e.g. structure, participation, knowledge, etc.). The aim is to use the principles of orders of agility to understand the construction of the 'decision space' within which decision systems are operating. It also makes reference to forms of time: Kairos and Chronos.

Publication 5

Dodd and Alston (2009) take up the themes of Publications 1 and 2, but moving away from support to decision-making, towards working through different perspectives more formally and analytically. This

[1] The use of the concept of rationality here does not presume any objective notion of 'being rational' but refers to the point that each commander holds to their *rationale*, which is based on their needs, their capabilities, their view of the situation, and their ways of assessing likely outcomes.

is an acknowledgement that a subject's context and conditions are made up of other subjects (i.e. other agents, people, groups, organisations, etc), all of which have their own views and perspectives (usually different and maybe conflicting or contentious) on a situation. A conceptual framework is presented from which analytical frameworks can be drawn, such that the methods used for problem formulation and analysis have sufficient degrees of freedom and requisite variety to match the characteristics of the challenges posed by complex situations.

Publication 6

Dodd (2018a) expands on the work presented in Publication 5 and addresses the challenges faced by analysts in extending out from traditional forms of analysis and modelling towards more relational forms. This challenge puts more emphasis on reflective practice, people and relationships and so a Staged Appreciation is proposed as an overall guiding 'check list'. The paper then presents a small selection of illustrative techniques for engaging with social complexity. The techniques, guided by Staged Appreciation, add an insightful new dimension to knowledge sharing for understanding, and for reflecting upon the intricacies involved in socially complex situations. Staged Appreciation complements the analytical standpoint by taking a more subjective and reflective view of relationships, with the analyst becoming more *a part of* the socially complex problem as well as standing *apart from* it. Staged Appreciation offers a reflective way of working with Systems Thinking techniques and together they complement traditional practice. The paper draws lessons from holism, reflective practice and subjective analysis.

Publication 7

Dodd (2018b) returns to the concepts that might shape, extend, limit or re-focus a subject's set of choose-ables, that can then be thought of as that particular subject's *potential* in terms of their ways forward and degrees of freedom of choice. The paper presents a funnelling construct to depict the ways in which a subject's imaginable options might be being discounted or encouraged due to regulation, feelings of discomfort or capability respectively. The paper draws together Catastrophe Theory and Cultural Theory to offer new ways of analysing the shaping effects of relational contexts on a subject's choose-ables, that then act as a medium through which a subject is drawn to make choices. The strength of the combination of the two theories lies in their descriptive power of subjective, relational concepts that hitherto have tended to remain hidden and tacit. This final paper, which presents the central study area for this thesis, is an exploration of why a subject's circumstances and relational conditioning might shape or directly affect their choose-ables.

This final publication of this portfolio sets out the basis for the theoretical framework for the scoping of choose-ables. Publication 3 introduced a theory of choice to address the nature of choose-ables, as aligned to the first four catastrophe models. Publication 4 then introduced the possibility of extending into the higher-orders. However, there is no explicit reference to the higher catastrophe models. Therefore, Publication 6 and Publication 7 draw on the other publications, synthesising the theories discussed in the other publications so that it is possible here to present a seven-fold framework of orders of choice, based on the seven catastrophe models (see Table 2-4 in Chapter 2, Section 2.6), that addresses both the nature and the scope of choose-ables. This framework is proposed as being applicable for any choice-making subject.

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GLOSSARY

Abbreviation	What means or is taken to mean
AI	Artificial Intelligence
C2	Command and Control
CoA	Course of Action
CSH	Critical Systems Heuristics
CURES	Cranfield University Research Ethics System
ESRC	Economic and Social Research Council
JSP	Joint Service Publication
MOD	Ministry of Defence
MODREC	Ministry of Defence Research Ethics Committee
RPD	Recognition-Primed Decision-making

1. Background and Introduction

1.1. Background

There has long been academic study into decision-making. These studies and experiments look at different strategies that are employed in order that an option (usually a course of action) can be selected from a set of decision options. These strategies[2] tend to assume that the decision-making 'agents' are objectively rational and that selections are being made based on maximising expected utility or minimising probability of loss. An example would be the now questionable concept of 'homo economicus' or rational man (Persky, 1995). An alternative, but related, approach is that of Recognition-Primed Decision-making, within the domain called Naturalistic Decision-making (Klein, 1997), where the strategies for course of action selection tend to be based on satisficing: "Evidently, organisms adapt well enough to 'satisfice'; they do not, in general, 'optimize'" (Simon, 1956; p129). These decision-making models and methods typically involve finding solutions to bounded problems whose objectives span a finite set of options associated with known patterns. Such methods are very suitable when the problems under consideration can be represented in closed-form, when it is meaningful and acceptable to bound the subject of interest for the purposes of arriving at an observable, objective, active solution to 'the problem' or coming to a selected decision-option given the situational pattern.

There are not, however, many studies into how the options for choice are settled upon in the first place. It is this subject of choice-making that is the focus for this research study, which covers the subjective nature of choices being 'imagined deemed possible' in the form of choose-ables (Shackle, 1976), as related to what that subject might be sensing and understanding. A subject's choose-ables are ways forward, that a subject has to construct, compose or create before they can choose: "*Your list of choosable things has to be constructed or composed by yourself before you can choose"* (Ebeling, 1983; p6: Interview with George L S Shackle). Choose-ables are a subject's options for choice, given the nature of their sensing of their context and of their felt conditions. In this respect choose-ables are both subjective and relative, leading to the proposition that any subject has an associated range and scope of choose-ables, and that these can be ordered (or nested) according to the nature of the choices open to that subject.

This thesis is not only concerned with humans as subjects, but it is also concerned with relations and 'between-ness' and, as such, it spans a range of 'beings' that can be classed as subjects; from agent-based algorithms and cells through individuals to organisations and political institutions. For each of these subjects, a set of choose-able *ways* forward is being constructed or composed and then, in differing manners, these are being considered and countenanced by the subject before that subject can choose between them. This gives a more subjective and adaptive treatment to the concepts that are traditionally and classically addressed in decision theory (e.g. decision options with associated pay-

[2] The strategies were comprehensively reviewed and critically discussed by Simon (1966).

offs); and also, even in Critical Systems Heuristics[3] (Ulrich, 2003) that takes a system's viewpoint of subjects rather than a subject's systemic viewpoint.

A specific subject (whether it be a person, a cell, an organism or an institution) is likely to notice, attend to or focus on information (or input) that is more fitting to their current state, preferences, immediate interests or needs. Any limiting of these subjective preferences, interests and needs relates bi-directionally to limits placed on choose-ables. These limits may be placed, tightened or relaxed for reasons of survival, security, competence, comfort and confidence; also, they may be related to felt contextual constraints, such as functional energy or expenditure limits, both of which could be assumed to have natural or prescribed bounds (e.g. energy limits or budget constraints). Alternatively, they could be related to drives or motivations that could extend choose-ables into more extreme regions of choice; for example, what might drive an individual towards more extreme forms of choose-able. It is this particular kind of sense-making (i.e. about a subject's way of framing themselves and their context around their choose-ables) that is the focus for this thesis. This is not the usual approach to sense-making, which is generally about how people and/or organisations frame their (usually retrospective) view of a situation 'out there', and from which they have selected cues to fit the patterns formed by their frames (Weick, 1995; p.xi):

> *"You are being thrown into the middle of a sensemaking conversation with only a vague idea of how it constitutes a perspective."*

So, this thesis looks at sense-making in a way that addresses what 'constitutes a perspective' for any subject where this perspective is strongly related to the nature and scope of a subject's choose-ables. If a subject becomes wedded to a single preferred way forward then the information that they attend to becomes more focused on what appears to determine that preferred way forward as being their choose-able way forward. If a subject is torn between just two alternatives (X or Y) as their choose-ables, then their sensing of information tends to become discriminatory (i.e. to serve the discrimination of their situation into either being A or being B) such that the choice to do X or Y can be efficiently served. This tight focusing and framing, then tends to reinforce the current choose-ables. Any subjective evaluation tends to be pre-defined by the self-imposed boundary conditions, within which the choices are being made. Any limits placed on the imaginable, deemed possible choose-ables, according to the boundary conditions being felt and the values being subscribed to, in turn may then tend to limit a subject's sensing and sense-making. These boundaries and limits determine the nature, range and scope of a subject's choose-ables, separating them from other possibilities that are not imaginable or deemed to be countenanced, contemplated or considered. There are orders of choice that may then be responsible for setting or re-setting the boundary conditions for any subject. For example, institutional conventions or constitutions can determine values, principles and beliefs, making their subjects' world more 'black and white' or about 'us and them'. Where a subject might feel itself to *be* is a key factor in the way that subject holds to choose-ables and thence senses, understands and makes meaning within its own world.

Some illustrative examples help to explain what is meant by such orders of choice. The first is where the subject happens to be an individual in a democratic society or community where there has been a choice made by a political leader (the leader being another form of subject with their own array of

[3] Critical Systems Heuristics developed formally from original work by Churchman (1982).

choose-ables) to hold a referendum. The ways in which the choices on the referendum paper are presented, received, understood and appreciated tend to reflect the conditions that brought about the referendum. If the text of the referendum paper offers only a binary choice then the nature of the socio-political context may be understood to be one of division[4]; indeed, then the reading of the choices, as made, could be seen to be potentially divisive. Generally, a society, with its ever-changing expression of needs and preferences, is anything other than simply being 'this way or that way', 'in or out' or 'us and them'; yet the socio-political context, prior to a binary form of choice-making, has by definition become divided and the 'seeing and believing' of subjects then tends to emerge as binary and divisive.

Another example is where the subject is a eukaryotic cell (Dodd, 2018c). In conditions of munity, a eukaryotic cell, according to its name (i.e. "eu"), serves the wellness of the body as a whole. As such, a cell is in collaboration with its mitochondria to serve the needs of the body. This wellness of being depends on cell apoptosis, brought about through an established mutual relationship between the cell and its mitochondria. As long as the collaborative interrelationship (maintaining the communal cell-mitochondria open boundary) remains in a stable state of comfort, then functional cell renewal continues. However, interrelationships associated with dis-ease and discomfort can conditionally create a potential for relational confusion. Cells may not readily differentiate and their destabilised, discomforted state may open-up possibilities (i.e. choose-ables) for a cell that would not normally be open for choice. If, at the same time, there is a shift in the vital balance of oxygen and glucose available to the cell, then the opportunity for an evolutionarily focused adaptation for cell survival may open-up as an extreme form of choose-able. This could lead to unlimited cellular growth.

The orders of choice framework can be used to describe such extreme adaptations in cell potential in terms of their response to sensing a survival-need discomfort[5] and a sense of aporia[6]. In such circumstances, the cell could find access to an evolutionarily-deep choose-able made open to it due to its sense of having no other way forward. If the cell adapts at the self-other and self-boundary order of choice (Figure 1-1) in order to survive, then the boundary relation with its mitochondria would need to become one of 'cell as self' and 'mitochondria as other'. The cell then has a new form of 'selfish' potential, such that it no longer has to be in tune with the needs of the body as a whole; yet the other protective cells around it (e.g. immune cells, blood supply cells) continue to sense it as an 'own' cell and strive to preserve its comfort. Essentially the eukaryotic cell has become an atypical, or cancer cell, whose choose-ables need now to be based on a concept of value that is no longer one of the whole body's 'eu'. This example is more about cells as subjects, being in the spirit of Kauffman's (2008) 'adjacent possibles'; another is slime moulds that, in abundant conditions, live as single cell organisms yet, when resources get scarce, they communicate to become a multi-cellular organism. So, slime moulds have a choose-able as an adjacent possible that affords them a vital re-structural survival possibility under extreme conditions.

[4] Necessarily there will need to be a boundary setting the delineation between self and other. It is in the nature of this boundary where the complexity resides. If the delineation appears to make the choice clear-cut, the 'solution' then appears to be clear-cut; however, it may be seen as anything but by other subjects.
[5] In social terms, Maslow's (2012) 'hierarchy of need' is relevant and useful here for understanding motivation.
[6] Aporia can be described simply as a sensed state of having no way forward.

This phenomenon can be seen to be just as readily applicable to institutionalised humans that are driven towards extreme choose-ables. An example of this move to 'mutiny' in institutions is where a subject is being held to institutional norms and cultural behaviours. These are generally designed to hold everyday business 'in check' but when everyday business pushes-up against personal concepts of value then individual[7] discomfort can grow. Then, despite being institutionally encouraged to ignore what is happening in their immediate context (Menzies-Lyth, 1998), a subject is driven towards more extreme and potentially challenging choose-ables, such as 'whistle-blowing', even though that may be potentially damaging to self. Another example is being an extremist, which in terms of choose-ables and orders of choice is of a different nature to being a criminal. If a legal system only has choose-ables that behave toward extremists in the same way as criminals then ways of seeing and making sense of extremists will be limited, leaving the system open to misguided reform programmes and potential emergent shocks. A related, more open example, and one that refers directly to 'grid-group culture theory' (Douglas, 2008), is around the concept of 'radicalisation', and, particularly in the UK, preventing radicalisation. If radicalisation were to be approached by appreciating and addressing changes in a subject's relationship with their context, working through an addition of potential in the form of more extreme, more radical[8], choose-ables, then prevention policy could refer to the deeper orders of choice to explore in what forms this potential may be being shaped.

In addition to Weick's (1995) work on organisational sense-making, and in relation to Douglas's (2008) work on organisational and institutional cultural effects on choice-making, the work by March and Olsen (1976) discusses the messy process of making choices in organisations (in particular educational organisations), where there is proper emphasis on matters of uncertainty and ambiguity of people. As such, it is the process of people exploring the nature of the problematic situation and, in that process, exploring the nature of their relationship with the problem exploration that becomes the important focus. This thesis proposes that the orders of choice framework will support such decision-making, sense-making, problem exploring and choice-making processes by providing a frame of reference for the subjects involved in those processes. This is explored further in Chapter 5 Section 5.5 where the orders of choice framework is applied to Reflective Practice and the exploration of messy problems.

The orders of choice do not in any way represent a set of choices that go from being basic to better. Their ordering is based on the nature of choose-ables, as being open for consideration by any subject for the purpose of maintaining a sense of its own viability, sustainability and avoidance of discomfort. For example, the choose-ables might be concerned with responsive choices, such as the active moves that are imaginable and accessible to maintain physical comfort when, say, a subject might sense a change in ambient temperature. Choose-ables could also be concerned with maintaining relational comfort when any subject senses that their inter-relationships are becoming unmanageable; here, for example, a possible choose-able might be a choice to make an ally into an enemy. These choose-ables are of a different nature and are according to a subject's sensed changes in circumstance that may be being interpreted as impinging on them through their sense of need for more comfortable settled-ness. In this thesis, it is assumed that the subjects are trying to preserve, or move towards, this multi-faceted, multi-layered sense of need for settled-ness; hence the importance of invariance as a central

[7] The concept of in*dividual*ity itself is important and is discussed as being an 'individualist' in Dodd (2018b).
[8] Here radical is being used more etymologically in terms of going back to their roots.

concept of subjective 'settling' (Noether, 1908). Noether's (1908) work[9] was based in mathematical physics where natural physical 'pulls' (e.g. gravity) result in consistent emergent behaviours, relative to the system in its environment (e.g. rolling a ball down a slope in the arctic exhibits symmetric behaviour to a ball being rolled down a slope anywhere else on the earth's surface). The catastrophe models assume a similar 'pull' (toward minima) so using these models is a way to bring the concept of invariance more into the socio-subjective setting of choice-making. This central theoretical concept of invariance then sets the choice-making landscape for subjective adjustment and adaptation[10]. So, a key assumption is that, irrespective of the order of choice, each subject will be making choices according to a principle of invariance based on their preservation of comfort. The different forms of subjective discomfort will tend to be manifested as a need (or drive or motivation) to address choose-ables at whatever levels of adaptation are imaginable and can be deemed to be open and accessible for preservation of that subject's enduring comfort and prevailing self-stability (Damasio, 2018).

There does not appear to be any kind of framework that might help to examine or explain why, within certain contexts and under different conditions, a subject may or may not be able to imagine, and then deem possible, extended degrees of their choose-ables. Therefore, the key research question driving this thesis and the presented publications is:

From where might a subject's choose-ables emerge; and how might these choose-ables moderate, or be moderated by, that subject's sense-making and their focus of attention?

In summary, this thesis covers the subjective and relational nature of what is imaginable and deemed possible, and also the subjective nature of what is being received, attended-to, noticed and comprehended; to what degree, and according to what kinds of frames of reference, and why.

1.2. Introduction to the topological shaping of choose-ables

The topological dynamics of Catastrophe Theory (Thom, 1975) provide a basis for visualisation of the different landscapes of options, choices and possibilities, all or some (or even none) of which, a subject may be able to see, imagine, attend to, comprehend or make sense of. This thesis develops a theoretical framework through reference to the seven catastrophe models (Zeeman, 1977). It also reviews other schemes, based on seven levels or orders, and combines these schemes into a generalised relational framework. The thesis builds into this relational scheme a recognition that a subject may appreciate or attend to the options, choices and possibilities presented at various orders in a partial or incomplete manner. It may be that there will be logical options, or classes of option, that are not imaginable by the subject, or which are suppressed from some contextual consideration (e.g. by an awareness of some blocking condition, such as need for survival, subscribing to an institutional convention or blindly adhering to a social taboo; or being considered to be out of scope or 'above my paygrade'). The thesis reviews the logic of the various orders, levels or schemes, and offers a nested seven-order framework, in which the schemes are further enriched by the

[9] Noether's (1908) theorem applies generally from planets to sub-atomic particles and so the translation being made in this thesis into the socio-subjective is consistent as it works across a similarly wide range of subjects.
[10] These being about a subject moving towards somewhere that feels more right or more apt.

psychological, ecological, developmental and cultural capacities that would enable them to be exploited by any subject; as well as the logical, biological, psychological or cultural factors that could inhibit such exploration and exploitation.

From an empirical point of view, it is feasible to construct domains, contexts or situations in which the concept of orders (or an ordering of levels or systems-levels) is missing or is suppressed. Morgan (1997) draws from Bohm's (1980) work on unfolding relations, making an important distinction between implicate and explicate order, where any seeming autonomy being seen in the explicate order always depends on the deeper implicate order. Autonomy and self-rule, with respect to decision-agents, are discussed in more detail in Publication 7. The point here is that what is observed (explicated) is dependent on deeper (implicated) conditions or conditioning.

If the concept of 'conditions' is taken to embrace the characteristics of domains, contexts and situations, then it may not be possible, in practice, to see an 'implicate' seven-order scheme fully instantiated. It may only be possible to see an explicate manifestation in a particular setting[11]; as Morgan (1997; p371) points out, by reference to Bohm (1980) who: "invites us to envisage the universe as an unfolding set of relations". This suggests that there is a depth of changing relations that runs through aspects of choice and, in particular, of choice-making and choose-ables. This thesis proposes that it is these unfolding relations that shape a subject's choose-ables, such that the shape-changing dynamics create a kind of adaptive potential for emergent, eventual observable forms and behaviours.

1.3. Research Scope

The subject of choice, in particular choice-making and choose-ables, is central to this thesis. It does not go so far as to suggest that the nested orders of choice provide any kind of generative framework that can be used to 'predict' behaviours based on the nature of the choice-making. Therefore, this thesis proposes a classification framework for what could be seen as a nested set of 'systems levels' and this is presented as a nested framework of orders of choice. These would pertain to seven different natures of choose-ables as illustrated in Figure 1-1 below:

[11] It is important to note here that the thesis is not in any way offering tactics or strategies for a 'rational agent' to explore the different orders (e.g. exhaust lowest first before considering higher orders); indeed, the proposition is that subjects will tend to be subject to all orders of choice, both implicitly and explicitly.

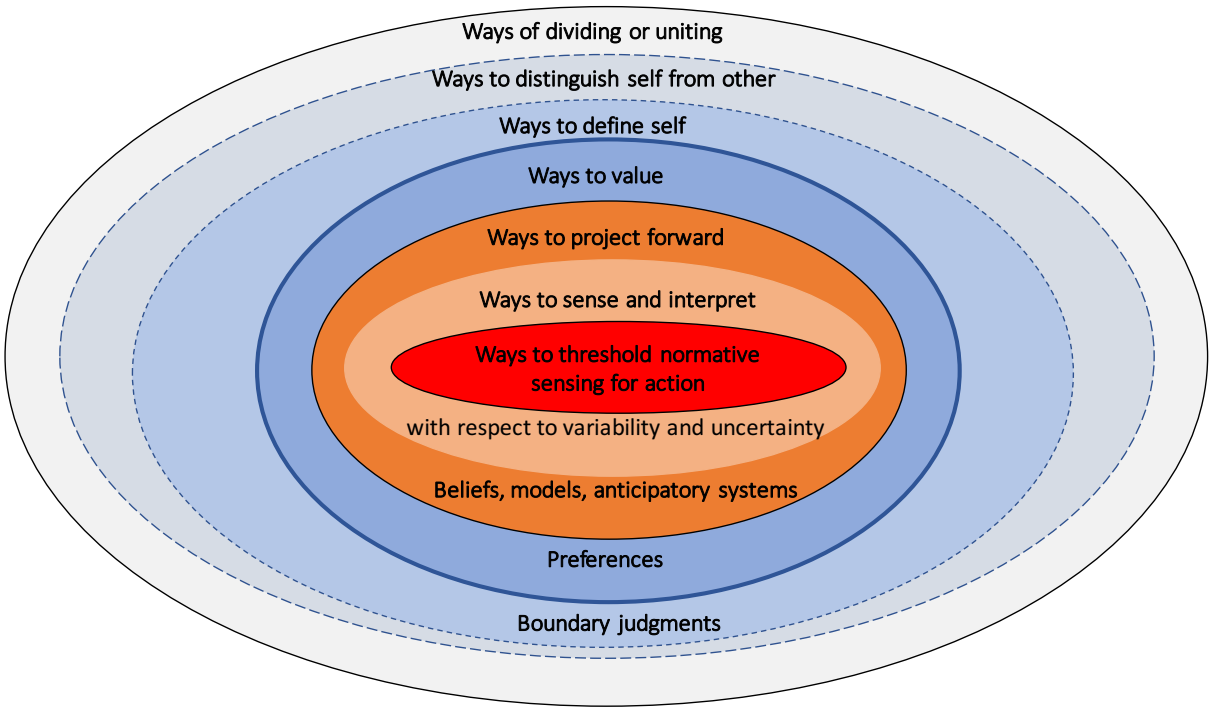

Figure 1-1: Illustrating the seven nested orders of choice (Source: Author)

Figure 1-1 is an extended context diagram used to illustrate the nested form of the orders of choice. Working outwards from the centre takes orders of choice from being choices about responses to immediate context (as in the centre) through those relating to variation, anticipation, evaluation (i.e. the next three-layers moving out from the centre). Extending outwards from here is where the self-boundary choices come into play, and, here, the context boundary lines are dotted because the orders now are very closely inter-related. In summary, the way in which the orders of choice can be described is shown in Table 1-1 (from inside-outwards in Figure 1-1).

Table 1-1: Natures of choose-ables according to orders of choice

Nature of choose-able	**According to ways of:**
Threshold	Sensing positional deviation from norms for thresholding.
Variative	Sensing, interpreting and sense-making in uncertainty and variability.
Projective	Projecting forward in time: anticipating, believing and modelling.
Valuative	Valuing perspectives, preferences and appreciating concepts of value.
Self-boundary	Setting boundaries between self and context.
Self-other	Distinguishing others in relation to self; e.g. friend or foe or person.
Divisive	Dividing-up or uniting the context; e.g. male/female or black/white.

Many factors might be open for choice within any bounded subject, including a choice about the subject-boundary. The choose-ables, therefore, might range from where attention is being focused, and might extend to what values are being adopted or questioned in order to stay within the bounds

of a societal collective. If a subject's held values are being challenged, then the subject's self-boundary may need to be adjusted and the nature, scale and scope of the information being addressed could also be involved. It is this inter-related aspect of systemic adaptation and holistic shaping that this PhD study is concerned with; in particular, the orders of choice that become significant when degrees of comfort are being challenged at the same time as they need to be preserved. Therefore, these orders of choice address inter-relationships and relative boundary conditions (e.g. self and other) rather more than is usual in traditional decision studies.

Another way to view Figure 1-1 is as if looking down on a metaphorical iceberg, where only the resultant potential action options, emerging from the choose-ables in the central-zone, are readily visible 'above the surface'. The Iceberg model, shown at Figure 1-2, is used in Systems Thinking[12] to make the point that patterns of behaviour, mental models, values, beliefs and culture all lie beneath the surface (or are sub-threshold). A three-layer iceberg model is used by Schein (2006) to address organisational culture with the three layers representing artefacts (i.e. what lies above the surface and can be seen), and values and assumed values, making up the larger part of the iceberg and lying below the surface. This iceberg metaphor will be returned to in Chapter 2, Section 2.5.

Earlier than Schein (2006), Hall (1989; p127-8) takes an approach to culture that sets capacity for change in terms of a subject's relationship to their context, characterising subjects according to being high-context or low-context cultures, which then are related to capacity for foreseeing and dealing with future potential confrontations:

> "*It is easier to foresee coming confrontations in low-context cultures than high-context cultures because the bonds in low-context cultures are somewhat fragile, so that people can move away or withdraw if things are not going well. In the high-context culture because the bonds are so strong there is a tendency to allow for considerable bending of the system."*

This approach to culture highlights the importance of considering a subject in relation to their context. Hall (1989) also discusses events that then appear to come without warning in high-context cultures that tend to create sudden jumps into over-reaction. This sets out a need to draw together cultural theory with discontinuity theory. He suggests that with respect to working through the effects of context on subjects: "*one can only guess what the total implications are*." This PhD study aims to provide a way to inform and support understanding of potential implications to avoid it being based on guesswork.

[12] See Donella Meadows' Institute link for Iceberg model and other useful systems thinking resources, at http://donellameadows.org/systems-thinking-resources/ (accessed September 2019)

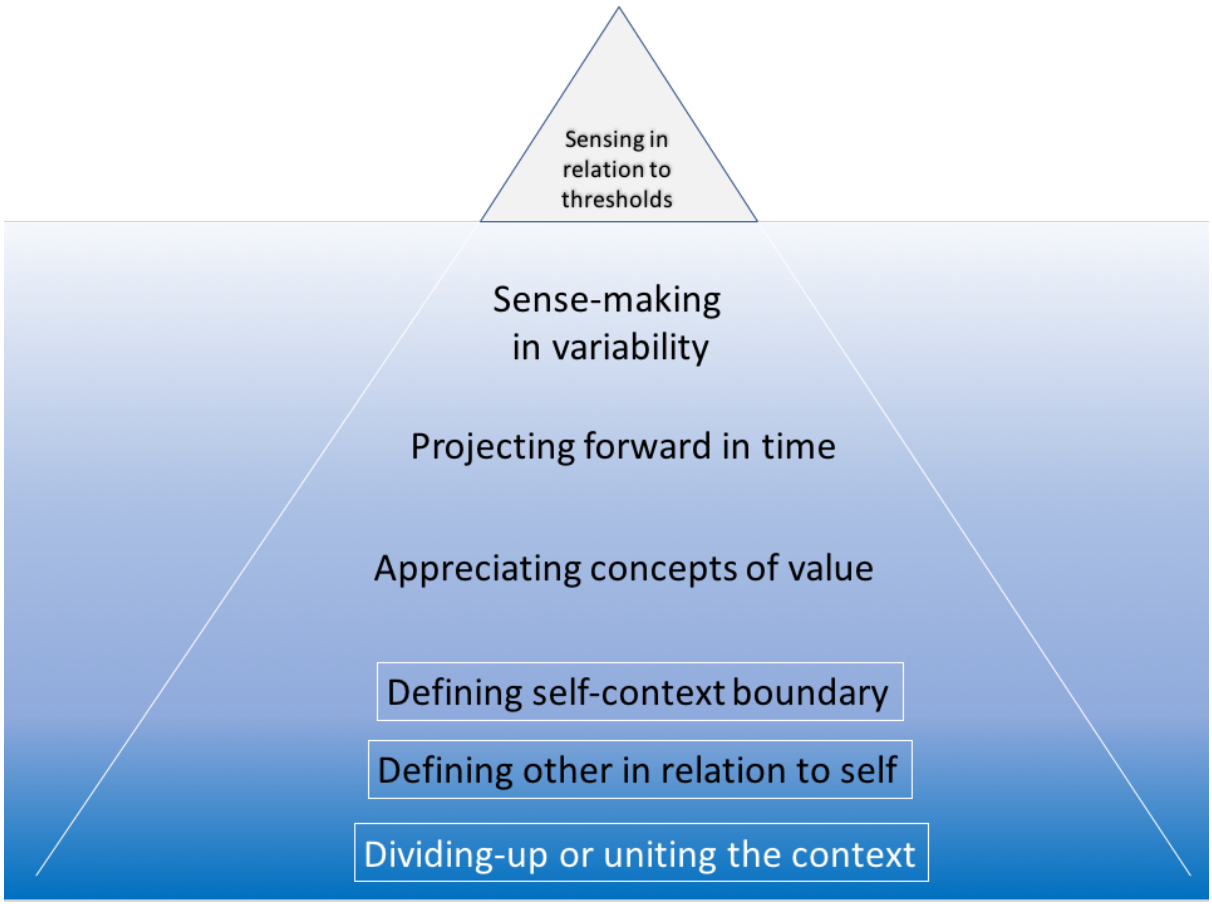

Figure 1-2: A view from the side using an iceberg metaphor (Source: Author)

1.4. Terminology and concepts

The study area of choice-making needs to be distinguished from that of decision-making, with its options and alternatives, which classically involves decision agents that "must choose among a set of alternatives displayed before him or her in a particular situation" (Allison and Zelikow, 1999; p18). The main concept in this thesis is one of choice; in particular, the subject's *making* of their choices through their imagining of potential ways forward, and their deeming of them to be possible; hence, becoming labelled as a subject's 'choose-ables'. The word 'choice' however, has many different uses and meanings ranging from an option presented (usually as a set of options or alternatives for choosing between) through to the option that has been selected as 'the choice' option (usually according to some process of optimisation). Here, there is experimental evidence, across a range of different subjects in different decision-making environments, that there is a need for subjects to preserve a form of cognitive consistency, which tends to be marked by values, beliefs, attitudes and preferences (Simon, 1985). It is useful to note here that a subject's appreciation of value is bounded by, and interpreted by, the subject's perception of reality since "facts are relevant only in relation to some configuration of fact" (Vickers, 1964; p54). Simon (1985) goes on to emphasise that a subject's characterisation of their choice situation then tends to form the basis for observed emergent

phenomena. One of these emergent phenomena might be discontinuities in risk aversion and reliance on heuristics (Kahneman, Slovic and Tversky, 1982). So, even in the study of areas of decision-making and policy-making, the tenets held in this thesis are founded in previous seminal studies of decision-making and policy-making.

The concept map at Figure 1-3 sets out the terms and concepts relating to order of choice and choose-ables to show the area of study covered in this thesis and to distinguish this area from other areas of study where the term 'choice' might be used to mean a selected option. Concepts such as 'choice' and 'order' are used in specific ways, as depicted in the concept map. The usual connotations of using the term 'choice' are included in the concept map as extensions to the top-right to show the related areas in decision-making and expectation theory that are excluded from this study.

1.5. Thesis Structure

The Thesis is organised in the following manner:

Chapter 2 presents a review of the broader literature, where other types of levels-based schemes have been defined and are also used in practice. It goes on to describe the theoretical basis for the seven-fold orders of choice framework. Chapter 3 sets out the research methodology, particularly the ontological journey through the seven publications based around the development of the orders of choice framework. Chapter 4 presents the seven publications set against the central narrative of the thesis. Chapter 5 covers the conclusions, discussion and recommendations: examining the orders of choice framework with a view to future application.

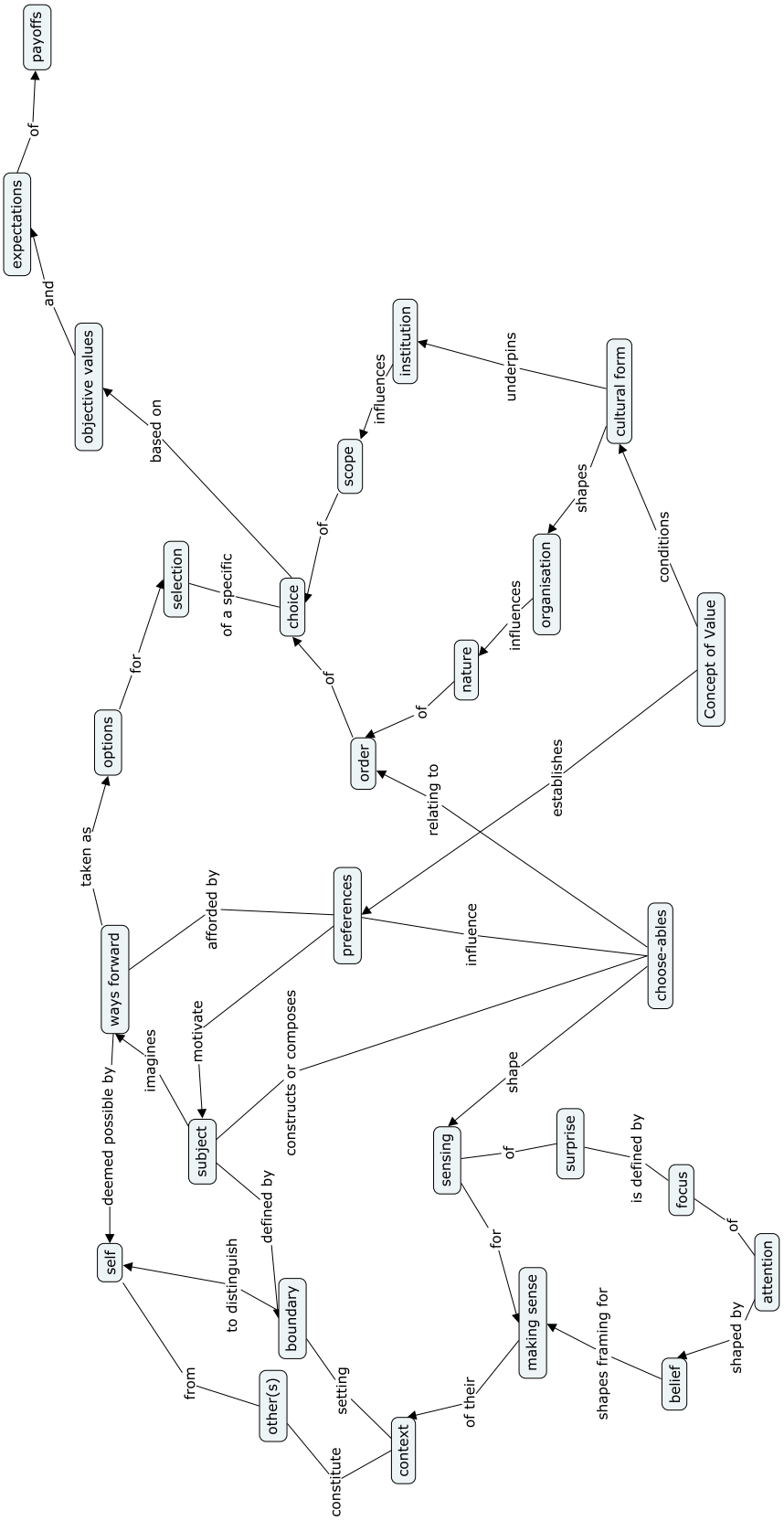

Figure 1-3: Concept map to clarify area of study (Source: Author).

2. Literature Review

Chapter 1 set out the background for the study and introduced the key topics and research scope. The purpose of this chapter is to review the literature that is implicitly, but not always explicitly, covered in the publications presented in this portfolio; however, it is this relevant literature that develops the context for the orders of choice framework, and also establishes the research gap that is being addressed by this thesis. This chapter therefore reviews key areas of literature where other types of levels-based schemes have been defined and are also used in practice; it then addresses the broader literature, covering some of the main subjects in the seven publications, in order to set-out the research gap. Sections 2.1 and 2.2 set out the background for levels-based schemes. In Sections 2.3 and 2.4, the discussion turns to relational distinction and how relational conditions might combine with drives, motivations and capabilities to shape the subject's choose-ables, according to what needs to remain invariant for the subject. This shaping is according to whatever or whomever might be making a choice, and can explain the ever-present biological need to sustain self in relation to other (Maturana and Varela, 1980; Mitroff and Linstone, 1993). Section 2.5 sets out the research gap. Section 2.6 introduces the mathematics and outlines the orders of choice framework to show that it addresses the research gap and also provides a way to approach and answer the research question. In Section 2.7, some illustrative examples from the wider literature are used to show how the topological forms, within each order of choice, can be used to explain changes in choice potential.

2.1. Background

Over many years of developing and running courses on systemic thinking and reflective practice (Schön, 1983) for people making choices in complex situations, personal experience has increasingly suggested that the teaching and practice of analytical skills might benefit from a more subjective approach (Schön, 1987). The situations being faced tend to be more socially and relationally complex (Ulrich and Dash, 2013), and any interventions and proposed solutions therefore need to be 'clumsy' (re)solutions (Thompson, 2008), rather than optimal solutions; also, as projects have become increasingly participative (Ormerod, 2008), and the projects that subjects are involved in have become more interconnected, there is a call for more reflective practice. This asks analysts where they stand in relation to others involved in the situation and calls for a way for analysts to develop a more reflective capability for self-assessment (Ormerod, 2013). A Staged Appreciation 'check-list' is presented in Dodd (2018a) that works through 'where subjects are' in relation to their perspective on context, their sensing and sense-making; also, importantly and with respect to their choose-ables, where their capability, capacity, ability and competence will play a part when forming preferences and beliefs.

With respect to strategic analysis, this positioning of 'where subjects are' is discussed in terms of orientation (as it relates to the Prospective order of choice) through challenges presented in the use of 'scenario planning' (O'Brien, 2004). The importance of *orientation* (Mathieson and Dodd, 2004) in

the strategic process of 'sense, sense-make, choice-make' is clearly highlighted in O'Brien and Meadows (2013; p20) with organisation and people being the subjects of study:

> "*It is important to place the organisation within the scenarios to understand what it might be like to operate within such environments. An exploration of how other stakeholders appear in the scenarios may be a useful additional activity at this stage*."

The placing of the organisation *within* their possible future circumstances develops their imaginative potential, enabling them to see themselves there and to deem possible some new ways or new structural forms, and then to extend their choose-ables to give more robust strategies in terms of potential ways forward. It also encourages people in organisations to imagine and explore their perspectives in relation to others' perspectives. This may have the added benefit of drawing out preferences and beliefs that may be inherent in unspoken and unexplored worldviews.

Use of complexity studies to make such worldviews more explicit enables the worldviews of different subjects to be seen as *a part of* the social complexity. Boulton et al (2015) fully examines this issue of social complexity within a real social setting that sets-out a meta-theory of implementation when engaging with social complexity, as defined by Johnson and Boulton (2014). The 'Adapt' stage draws out subjects' expectation-based beliefs and preferences as they are encouraged to be prepared for unexpected events and to be able to think through into unintended outcomes. This open-ness to possibility and readiness to adapt also draws attention to value-based goals that can be then made more open to opportunities when making choices. This aligns well with the principles outlined in the Adaptive Stance (Grisogono, 2011).

It against this background of academic rigour, both in terms of developing strategic analysts and also setting out the need for new theoretical approaches for engaging with social complexity, that this thesis develops a framework that supports the drawing together of these two fields of research. The orders of choice framework presents a way for different subjects, including the analysts themselves as sense-makers and choice-makers, to be appreciated for their part in the social complexity. It provides an explanatory framework for 'where subjects are' in relation to their context, where this context is made-up of other different subjects, all of which have differing rationales for their ways of sensing and sense-making, as related to their scope and the nature of the choose-ables.

2.2. Background to levels-based schemes in the academic literature

This section introduces schemes based on levels or orders, and sets the background for combining the concepts in these schemes into the seven-fold nested framework for understanding orders of choice. In this thesis, the theory of choice and choice-making (Dodd, 2011) is expanded on in terms of the two most recent publications (Dodd, 2018a; 2018b) that draw out two important aspects relating to:

- Text and context (i.e. what, in terms of the text, forms the focus for choice within, and then what sits without, in terms of the context, that shapes the choose-ables); and
- Reflection (i.e. what capacity might be open to a subject to reflect on, or adapt, the boundary being set between text and context).

With regards to text and context, firstly, there are structural couplings (Hoverstadt, 2010) (or, more generally, inter-relationships) between what lies in context and what might then be seen to emerge in the form of the text. It is assumed that it is the boundary conditions and hence the emergent 'text' that form the nature of a subject's choices and the scope of their choose-ables. With regards then to reflection, what might be seen to emerge as 'text' may be being subjectively obscured, filtered or enhanced due to the nature of the choices that a subject feels open-to within the scope of the choose-ables.

For example, as discussed in Chapter 1, Section 1.1, what might emerge from changing patterns in a socio-political context could be manifested in the text of a referendum ballot. The ways in which that text is received, understood and appreciated will differ according to what choices a subject feels they are able to make at that time. If the text of the referendum ballot offers only a binary choice between two options, then the nature of the socio-political pattern will be understood to be one of division; indeed, then the reading of the choices being made could be seen to be potentially divisive. Necessarily, there will need to be a boundary that sets the delineation between self and other. It is in the nature of this boundary where the complexity resides (Gabriel and Quillien, 2019). The binary delineation appears to make the choice clear-cut and so the 'solution' then appears to be clear-cut when it may be anything but. Generally, socio-politics, with its ever-changing expression of needs and preferences, is anything other than simply being 'x or y' or 'us or them'; yet the context, prior to a binary referendum choice, has become unnaturally divided and the choice-making emerges as binary and divisive. Any form of choose-able based in finding resolution or compromise may then become untenable.

Problems can then develop over time, as the nature of the simplistic divisiveness does not allow alignment with the complexity of the socio-political dynamics. Resolution requires an appreciative look (i.e. a re-spect) at the original division in order to draw out shared concepts of value from both sides of the divide. This allows a re-shaping of the flattened, in/out 'chequer-board' socio-political landscape so that it can resemble more of a multi-faceted, diverse fractal landscape that aligns more readily with the inherent complex nature of a socio-political population, through which the socio-politics has the affordance then for a diverse community to work coherently.

2.3. Making distinctions

One key distinction is that of self and context, and in particular self and other. This is highlighted and explored through a system-boundary study, drawing from Critical Systems Heuristics (CSH) and, in particular, the CSH triangle (Ulrich and Reynolds, 2010) in that the boundary is intrinsically linked to what, in CSH, are termed as 'values' and 'facts'. The nature of the self-other boundary distinction resides at the fifth and sixth orders of choice[13], working in concert with the concept of value according to related sensing and sense-making 'comfort-zones'; for example, reinforcement of self-based values then reverberates through the relational objectification of 'other', which may result in the 'other'

[13] This relates directly to the illustrative example of eukaryotic cell munity given in Chapter 1, Section 1.1.

being differentiated (e.g. named) as enemy or foreign. According to Espejo and Reyes (2011; p4), "naming a system implies distinguishing it from its background, separating its parts and relations from its environment by means of specifying a border". The proposition that a subject makes reference to such a boundary choice is a critical aspect of this study. A subject is then distinguished from its context, and yet is subject to what lies within as well as what is being shaped from without. What lies within a subject describes their current interest, focus, frames of reference and preferences. Espejo and Reyes (2011; p4) go on to say:

> "*We may enhance the number of distinctions we can make by using different observational tools…..our capacity for further distinctions may change as well." [however] "we do live in a world of shared regularities that we cannot alter at whim…this shared world is the outcome of an on-going process of cultural agreements and not an ontological reality 'out there'*."

Many researchers have explored boundary distinctions (Spencer-Brown, 1969) and the nature of self through the concept of autopoiesis (Maturana and Varela, 1980). Isaac and O'Conner (1976) took a central idea of a dynamic element being the self-object relation and made a distinction between an operating unit (i.e. managing interactions between subjects) and an operating unity (i.e. being a relational whole). Isaac's (1976) central idea of the subject-context-relation *being a dynamic element* places an emphasis on co-evolution of the creator/receiver 'self' as subject, and is now given more depth and breadth due to the many structural forms that 'self' can take; for example, individual cell, organism or person, organisation, institution, nation state, group, team, cult, family, tribe, etc. The very existence of distinction, seemingly vital for human subjects to make sense of their world and of choosing and acting in that world[14], can set-up some structural traps; for example, groupthink, institutional thinking, etc. This relates to co-evolution of self-other forms of distinction and it also begins to capture how the structural logic might, in turn, feedback to ways in which observable happenings might be conceived, received, perceived, interpreted, etc. All of which depend on what a subject is, or is not, sensing, attending to, noticing, etc.

Systemic structural logics for learning and adaption are well researched in the literature (Emery and Trist, 1963) and introduce the useful construct of a 'causal texture'; however, this cause-effect view may draw the thinking about 'logic of the system' into a linear, chronological form and may restrict broader, conditional and relational understanding of orders of choice. Learning and adaptation systems (e.g. complex adaptive systems approaches (Grisogono, 2004)) work around a pro-active cycle of 'act-sense-understand-decide-assess/adapt/learn' within a defined boundary of 'self' and self-values (e.g. self-based concepts of value defined as Measures of Success) within an operating context. This opens up questions around self-context boundaries and does not need to be held according to any form of cause-effect logic, but takes more of a condition-potential stance. Whitehead and Russell (1913) describe these forms of time and change as potentially higher forms of logical type (Cocchiarella, 1980). This leads to a discussion of the forms that such systemic structural logic types might appear to take due to the subjective way of making distinctions.

[14] Angyal (1941) refers to two principal forms of being in the world: autonomy and homonomy.

2.4. Specific instances of levels-based schemes in the academic literature

Several instances of levels-based schemes appear throughout the systems literature. This section highlights some of the work that has provided inspiration and that has acted as a foundation for this PhD study. One example of a seven-level 'general systems' scheme is presented in Boulding (1956). Each system-level reflects a particular degree of system complexity. Of such general systems levels, Flood and Carson (1993) suggest that they gradually build in complexity in terms of their inter-relational intricacy. Such schemes are based on a view that subjects are systems that can operate at increasing degrees of complexity. This is useful but it tends to establish a behavioural 'one above the other' ordering of the subject-system observable life. The orders of choice, as presented in this thesis, are nested within each other rather than being set one above another. This is an important point because order of choice refers to the nature of the choose-ables, in terms of potential *capacity for choice*, rather than inferring any form of increasing scale of system complexity in behavioural terms.

Linden (1995; p254-255) summarises Smuts' (1926) holism conceptual scheme stating that there are seven levels that make up a whole: "these wholes are hierarchical and expansive" and, as such, gradually build in complexity in terms of the nature and intricacy of the structural relationships. In contrast to the usual 'organogram' view of organisational hierarchies, here hierarchy refers to being nested and holistic, capturing the feel for hierarchy as the way in which complexity organises itself. So, to emphasise this form of hierarchy, another example of a seven-level system of capability is developed in Jaques et al (1978). Stamp (1989) interprets the first five levels in terms of graduated development through nested levels of capability; importantly, each level is subsumed within the next and so 'development' is more in the sense of building upon and extending or broadening out into context. Isaac and O'Conner (1976) explain this as follows:

> *"In moving from one level to the next, a transformation of self and objects of the preceding level takes place; elements of the preceding level becoming integrated and serving as poles for the succeeding levels".*

This describes the nested form of the subsumed developmental levels, which is wholly consistent with the nested orders of choice. Isaac and O'Conner (1976), like Smuts (1926), referred to an operating unity as being different from an operating unit. In systems terms, an operating unit would be as determined, maybe by a Systems Engineer, as having a specified boundary and a declared purpose; being purposive rather than being purposeful. As Hitchins (1992; p76) states: "a purposeful system exhibits its own will". He goes on to note that: "purposive is the attribution of purpose by an observer outside the system" (Hitchins, 1992; p9). He offers an example to illustrate this:

> "*An aircraft is purposive, while its pilot is purposeful. Pilot and aircraft together become a purposeful system as long as the aircraft performs to the will of its pilot." (Hitchins, 1992; p76).*

Additionally, Waring (1996; p13) notes that purposive can be defined as "purpose without choice" whilst purposeful can be defined as "purpose with choice". It is this concept of purposefulness, as it relates to choice, that this thesis expands on and explores; along with the notion of an operating relational *unity* and what, within that operating unity, and as described by the seven-fold framework, shapes a subject's choose-ables.

There is, therefore, a logical developmental rationale behind the different forms of seven-levels scheme, which may be seen in terms of increasing degrees of systems maturity or scope of capability. This rationale can be explored through the order of choice framework developed in this thesis, as it applies to choice-making and choose-ables; however, it does not in any way imply a scale of developmental behavioural maturity. The order of choice framework is presented as an explanatory, descriptive framework that can assist in understanding why a subject's choices are what they are, due to the nature of their current self-boundary-defined context, as related to that subject's ways of sensing and making sense of where they are within their context.

The orders of choice can be aligned and associated with other 'levels' of complexity and adaptation. For instance, in Complex Adaptive Systems theory, there are four different levels of adaptation (Grisogono, 2004) that any self-defined system may make according to specific forms of feedback and feedforward depending on that system's Measure of Success. CSH (Ulrich and Reynolds, 2010) also emphasises the need to make explicit reference to a system's boundary, being relative to the system's purpose within a hierarchy of purpose (Kinston, 1986); although these too are usually declared according to a set of values or Measures of Success, and according to what constitutes evidential facts or information. Many factors might be subject to change within any bounded system, including a change in the system boundary. The choose-ables, therefore, might range from where attention is being focused, or might extend to what values are being questioned in order to stay within the bounds of a societal system. It is assumed that if choices are made that alter stated values then the boundary of the system may also need to be adjusted and the nature, scale and scope of the information being addressed or allowed would also be involved. It is this inter-related, nested aspect of systemic adaptation that the orders of choice are concerned with; in particular, when orders of choice become more or less significant as levels of comfort are being challenged yet need to be preserved.

Emery and Trist (1965) define four causal textures of organisational learning environments, in which organisational systems, as subjects, learn and adapt differently:

- *Placid randomised:* where all a subject can do is have short-term tactical choices for coping with the extents of the environment;
- *Placid clustered:* where there is survival value in becoming goal-seeking so long as the subject is not deluding itself about their frames of reference for clustering;
- *Disturbed reactive:* where the subject has to deal with lots of other different types of subjects and understand their relational positioning;
- *Turbulent:* due to the intricacy of inter-subject (or inter-institutional) couplings.

These four causal textures form a useful basis for addressing organisational orders of choice. They assume that the subject-environment boundary is a given. For them this operating unit, which is similar to what Angyal (1941) calls the biosphere, is a 'social field'. What needs to be recognised is that the operating unit includes both the subject and its defined environment. This means that the Emery and Trist (1965) levels of organisational environments are constructed at a higher level of abstraction than 'the system and its environment'.

Baburoglu (1988) describes a fifth *vortical* environment as a 'theoretical extension' to cover situations when a subject does not (or cannot) deal with turbulence. This assumes that a subject's sense of turbulence comes from within the subject and from their relationship with their context, due to the

nature of their choose-ables and their open-ness or closed-ness to sensing and of sense-making. One main point is that invariances in this environment are of a different nature, which would be supported by the orders of choice, where the invariances are extended out from the subject's self into their self-context boundary. In this regard, Baburoglu's (1988) work provides an important extension to Emery and Trist's (1965) causal textures because it turns the operating unit into more of an operating unity, where the inter-relationships of the subject are interwoven with the intricacies of their dynamic context; hence, in line with Isaac's (1976) relational dynamic element.

The following section covers in more detail the associated orders or levels-based schemes. It presents those schemes that are considered to be of a nested nature rather than being set-out in terms of levels of increasing degrees of attainable behavioural complexity or presumed 'intelligence'. As such these tend, by nature, to be organisational or structural, and align more closely to the orders of choice framework. The three such levels-based schemes, relevant to this study, are Morgan's (1997) metaphors, Beer's (1995) Viable Systems Model, and Stamp and Isaac's (Jaques et al, 1978) levels of capability. It is important here to also mention Hoebeke's (1994) work because he provides the practical link from the systems science concepts through to the realities of living in different forms of organisation.

Morgan's metaphors

Morgan (1997) uses metaphors to illustrate the different natures and forms of organisation where any subject can be imagined as being organised as shown in Table 2-1. Morgan's (1997) other metaphor called "Flux and Transformation" can be understood as overarching the ones listed in Table 2-1, where organisation is 'as enfolded implicit relations' to give appropriate emergent explicit forms consistent with context.

The usefulness of the metaphors for organisation comes in the presentation of a language that can be used to describe what might be taken to be going on *between* subjects; and also, within subjects. For example, when terms such as 'lever' and 'delivery mechanism' are used then a machine metaphor is being presumed; yet it may be that the reference is to a social situation. This metaphorical language is telling in terms of the choose-ables and the order of choice that a subject may then be expected to work with and within. These seven metaphors align well with the descriptive forms for the orders of choice; however, the distinguishing aspect of the metaphors is more about the nature of inter-relationship, whereas the distinguishing aspect of the orders of choice is concerned principally with the nature of choice. The metaphors do give support to the orders of choice through the different forms of purpose and concepts of value, and through being an example of implicate structural logic as a basis for potential explicate behaviour.

Table 2-1: Morgan's (1997) Metaphors for Images of Organisation

Metaphorical image	**Where a subject's form of organisation is as:**
Machine	Input-output mechanisms[15] accord to a set purpose (i.e. purposive)
Organism	Homeostatic feedback (e.g. biological feedback with purpose towards stability, equilibrium and homeostasis).
Brain	Neuro-cybernetic feedback (i.e. affording purposeful learning and adaptation).
Culture	Socio-cultural relationships (i.e. about managing shared purposes, and appreciating values, perspectives and lessons).
Political	Power relationships (i.e. about establishing power relationships and maintaining a balance of power).
Psychic Prison	Reinforcing relationships (i.e. about maintaining 'own world' that is then reinforced internally and set apart from other worlds).
Instrument of Domination	Divisive relationships (e.g. for establishing and maintaining institutional control).

Beer's Viable Systems Model

Beer's (1995) Viable Systems Model (VSM) details the neuro-cybernetic (or brain) metaphor to present a diagnostic model for organisational viability, which is related to requisite variety (Ashby, 1958). An organisation, or any sub-organisation, as long as it has autonomous function, is separated into three sub-systems as follows:

- The operational Environment of the organisation;
- The internal Operating units of the organisational system; and
- The Metasystem (or 'brain') whose function is to balance input from the environment with information from the Operating units.

These are usually diagrammatically arranged as in Figure 2-1, with the Environment drawn to the left-hand side, the Operating units in the lower-right 'body' and the Metasystem in the top-right 'brain'.

Figure 2-1 shows that there is a nested arrangement in that within the operating units themselves there is a self-similar structure. VSM is a diagnostic model of *an* organisation, whereas Morgan's (1997) metaphors refer to ways of thinking about *organisation* per se. VSM is founded in a neuro-cybernetic metaphor of organisation. This tends to bring with it a systems hierarchy (i.e. systems 1-5) especially when VSM is directly applied to specific hierarchical levels in an organisation; yet it is presented here because each of the systems essentially has a functional order of choice in that choose-ables at the different systems' levels are being shaped according to choices being *made* at other levels.

[15] According to Isaac and O'Conner's (1976) dynamic element, this mechanistic relation renders the subject as machine-like; as such, people become 'things' or mechanistic operating units or 'human resources'.

Also, VSM has a nested approach to application in that smaller, self-similar VSMs are embedded in the larger one (see the inner 'guts' of System 1).

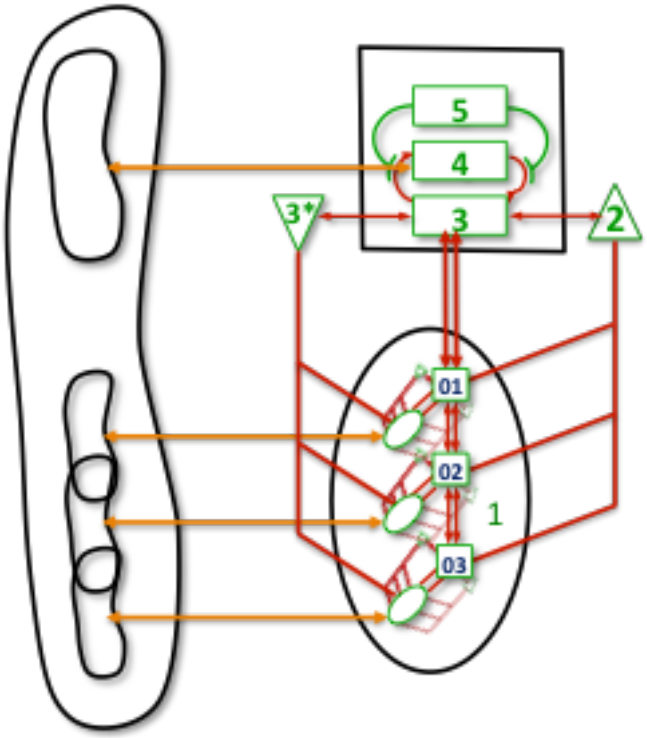

Figure 2-1: Schematic showing the five systems levels in a VSM model (Walker, 2001)

The systems levels are arranged (working from bottom to top of Figure 2-1) as in Table 2-2.

The nested, embedded nature of the VSM aligns well with levels of capability when these are relationally applied to Jaques' (1997) levels of organisation, which have an unstated structure based on "unless-cannot" (Stamp, 1990; p19); for example, a corporate mission "cannot be realised unless the themes of quality, service, practice, development, strategic intent, corporate citizenship and prescience are all woven together". It is this scheme of systemic structural logic as applied to a subject's level of capability that is examined next.

Table 2-2: VSM System Levels

System level	System Description
System 1	A collection of operating units doing the primary activities and in direct interaction with their environment.
System 2	A conflict resolution or coordination function responsible for system stability and operational functional stability across the operating units in System 1.
System 3	A management function responsible for purposive synergy, overseeing the 'here and now' managerial functions. System 3* is an associated management function that is responsible for monitoring (bypassing System 3) the overall running of the System 1 and System 2 functions.
System 4	An 'outside and future' monitoring, forecasting and planning function responsible for developing future views, challenges, opportunities, uncertainties, possibilities, etc.
System 5	Responsible for balancing needs and values across the organisation as a whole; in particular, the relationship between the 'here and now' management (System 3) with the 'outside and future' functions (System 4). In essence, when working effectively and holistically, System 5 maintains the organisation as wholly viable, in concert with its environment and with requisite variety.

Jaques, Stamp and Isaac's (1978) levels of abstraction capability[16]

The seven 'levels' (or orders) occur throughout relational developmental studies and a collection is provided by Stamp[17] (Jaques et al, 1978; pp16-17) giving a generalised overview of the first five levels in terms of development through levels of capability as in Table 2-3. The last two levels descriptions (i.e. Levels 6 and 7) in Table 2-3 are adapted from Stamp (1990).

[16] Jaques (1997; pp251-270) relates the capability levels to Requisite Organisation for engaging with levels of complexity: "*the term requisite organization means doing business with efficiency and competitiveness, and the release of human imagination, trust, and satisfaction in work*."

[17] There are additional descriptions and comparison tables of the first five levels in the chapter by Stamp (Jaques et al, 1978) entitled 'Assessment of Individual Capability'.

Table 2-3: Levels of Capability

Level of Capability	**Level Description**
Level 1	Concrete threshold/rule as the basis for *deductive choice* when the subject can be discriminated from an object of direct activity (e.g. having an internal skill to perform a contextualised action).
Level 2	Ambiguous thresholding for objectives with *inductive flexibility* in application of rules for accounting and co-operation (e.g. knowing when and how to apply rules and processes).
Level 3	'System' is introduced for managing and projecting (e.g. using trends of serial instances) to establish a goal and a plan (e.g. knowing how to look forward and manage planning forward in time).
Level 4	Abstraction and hypothesis building as rule-gaps, ambiguities and new perspectives appear as new duality (e.g. able to appreciate abstract relationships *between* rules, people, values, etc).
Level 5	More universal theory construction for place in a wider enterprise for societal goals, with uncertainty as a given (e.g. able to appreciate or establish balances to set *own* principles in and across a societal field).
Level 6	The capability is around corporate citizenship and ways to comprehend the different forms of context (e.g. economic, social, political, technological, religious, etc) and (where appropriate) encourage other levels to adopt and embed them.
Level 7	The capability is around corporate prescience and ways to bring into being current and nascent contexts for future generations (e.g. of being a single nation or as being inter-nationally corporate).

These levels can be related to time horizons in terms of the time taken for decisions at the different levels to come to fruition. This aligns with the nature of choose-ables across the orders of choice. Additionally, in Jaques et al (1978), the discontinuity of relational development across the levels is highlighted, which captures the discontinuous basis for the catastrophe models (Dodd, 2011). Moving from one level to the next does not imply any determinism as regards the content of the 'next level'. It is simply a property of previous levels being 'subsumed' into successive levels. The mathematical differentiation and integration is what moves a subject through the orders of choice (as in the Cuspoid models described later in this chapter and presented in Table 2-4). The dynamic element that Isaac and O'Conner (1976) talk about is a dynamic relation that refers to the changing degree of differentiation, or of integration/confusion, between a subject (e.g. self) and its context. The dynamic element leads to an operating-unity of self-structure.

System 5 in Beer's (1995) VSM holds to the same sense of balancing self with wider environment as does Stamp's (1990) Level 5. These both support the self-context (i.e. fifth) order of choice with also a shared sense of nested-ness to emphasise that the self-context boundary choices are being made within and across a range of scales.

In essence, these levels-based schemes are systemic and have a nested form of structure, and so they support the general construct adopted by the orders of choice framework; however, the levels-based schemes are presented in terms of language and diagrams whereas the orders of choice framework is based in topology and mathematics. This provides a more formal and rigorous framework for not only rationalising subjective, systemic potential but also analysing such potential with the possibility, therefore, of linking it eventually to explanatory models of systems behaviour.

Now that the levels-based schemes have been described and aligned with the orders of choice framework; and, before the seven-fold framework can be presented as a *novel* framework for understanding orders of choice, the research gap is identified and presented here as it relates to the publications in the presented portfolio (in particular, the work by Dodd (2011; 2018a; 2018b)).

2.5. Research Gap

There has been much experimental and theoretical coverage of decision-making and decision-taking in the academic literature in previous years (see, for example, Janis and Mann, 1977; Klein et al, 1993) but there is very little that covers choice-making (Sylvan and Voss, 1998; preface):

> "*Previous studies of foreign policy decision making have largely focused on the choice among specified options rather than the prior question of how the options were specified in the first place*."

This statement is supported most recently by Newell and Shanks (2014) when they review decision-making studies and state that theories in decision-making have not lead to adequate ways for assessing people's wider awareness. Recently, Klein's (2014) work has moved more towards addressing that issue but remains within a case-based analysis of observed behaviours of those making decisions.

There is no evidence of a formal, mathematical treatment of subjective choice-making; therefore, the theoretical framework provided in this thesis works towards a subjective treatment of choice. What makes an area of study objective and what makes it subjective? This is put succinctly by MacLean (1990; p5):

> "*The irony of the completely objective approach is that every behaviour selected for study, every observation, and every interpretation, requires subjective processing by an introspective observer….The sciences have focussed on the external world. By contrast, there has been a retarded interest in turning the dissecting lamp of the scientific method onto the inner self*."

Importantly, MacLean (1990) goes on to say that there is a need for some sense of agency for any form of communication (used here in the 'communing' sense of communication (Luhmann, 1996)). Maclean (1990) goes as far as saying that such 'subject-based invariance' might form a basis for a more general 'law of communication' that could be treated metaphorically and relationally, such that entities and information might be compared to particles and waves. It is not clear that this link from

community to quantum physics can be readily made but, through providing a subject-based structure for choice that is based on invariance, it may be possible to begin to consider and explore such links.

'Text' and 'context' are necessarily nested, which is why a classification framework of nested orders of choice seems to be an appropriate way of addressing the research gap. The mathematics of the, effectively nested, catastrophes[18] helps to describe, explain and explore the dynamics of topological landscapes, over and through which a subject's choices might be being shaped and formed. This choice-making landscape tends to be one of 'silent transformations' (Jullien, 2011) as précised in Dodd (2011):

> "*The world is full of tipping points and cliff edges but it is not clear what forms the slow dynamic that moves and shapes the underlying surface responsible for decisions and chosen actions. This theory could help with early warning of impending cliff edges in what often seems to be an otherwise smooth progression; at least it will help to prepare for making the most of the potential cliff edges as they offer up opportunities for transformation, structural change and growth*."

Jullien (2011; p158) describes the slow, continuous, silent transformations as a substrate for change from which structures emerge: "essential to us….as a necessary foundation". Therefore, a formal language is required with which to understand why discontinuity arises from what appears to be a background of gradual continuous change. The Catastrophe Theory (Smith et al, 1981) models provide ways of seeing the discontinuous edges, cusps and tipping points that emerge as the slow dynamics of the subjective conditions and circumstances work through the nested shaping parameters for choose-ables, giving rise to different choice potentials for eventual discontinuous behaviours.

The topological, relational dynamics of Catastrophe Theory (Smith et al, 1981) provide a choice-based language for visualisations that help with imaginative listening to the silent transformations and for seeing the potential edges and cusps. This study presents the seven catastrophe models in terms of orders of choice so that choice-making can be examined through what orders of choice are being referred to by a subject, and why. For example, are the choices about what a subject[19] may identify as foreign (i.e. being seen as non-self)? Or, are the choices about concepts of value? Or, are the choices more simply about available responses given an event or 'inject' intruding from the subject's operating environment? In this latter case, the nature of the subject's ways of sensing and being aware of their context tends to shape their degree of open-ness to surprise and their noticing of such events.

The nature of this choice-making (for the first four orders of choice) was introduced in relation to training needs for decision-makers (Dodd, 2009), as a conceptual framework where the orders of choice are set against types of knowledge (Detienne and Vernant, 1974): techne, episteme, phronesis and metis (these types of knowledge are explained in more detail in Chapter 3, Section 3.7, Table 3-2). This early work on the development of capability for decision-makers can now be linked to the earlier research in military decision-making that used a cusp catastrophe model (Dodd, 1994; 1998). The way in which this work has been taken forward in Dodd (2011) and then in Dodd (2018b) (and taken further in this thesis) is to develop the catastrophe models to give a framework for orders of

[18] The first four catastrophe models are introduced in Dodd (2011).

[19] This subject could be a biological cell, a nation state, an individual person, an institution or a group, etc.

choice and to associate these with a natural need for invariance balanced by an evolutionary drive for requisite variety.

The domain of 'order for free' in complex systems with 'powerfully ordered properties' is explored formally by Kauffman[20]:

> "*You have to ask a question that evolutionary theories have never asked: how do we build a theory that combines structural coupling, that facilitates both constitutive and behavioral autonomy and natural selection? There is no body of theory in science that does this. There is nothing in physics that does this, because there's no natural selection in physics; there is self-organization. Biology hasn't done it, because although we have a theory of selection, we've never married it to ideas of self-organization. One thing we have to do is broaden evolutionary theory to describe what happens when selection acts on systems that already have robust self-organizing properties. This body of theory simply does not exist.*"

Kauffman (1995) is stating a need for a new biology. This thesis proposes that the development of Choice Theory (Dodd, 2011), bringing together Catastrophe Theory and Cultural Theory, provides a stepping stone into such a new biology on the bases of requisite variety (Ashby, 1958) and invariance (Noether, 1918). There is a need here to discuss the concept of implicate enfolded orders (Bohm, 1980) as it is helpful to see them as unfolding to form a landscape for choice-making (Dodd, 2018b). Given this, the topological conditioning of an enfolded *potential* for choice can be formally described according to a nested integration, or synthesis, of orders of choice. The topological forms, within each order of choice, can describe impacts on choice potential due to adaptation in relational conditions (e.g. through differentiation or integration in terms of the declaration of a foreign state as an 'enemy' state; or integration in a company merger, or in the breaking-up of a coalition) to maintain a subject's sense of comfort in terms of their sensing and sense-making. These relational conditions then combine with drives, motivations and capabilities to shape the scope of choices available, by whatever or whomever might be making a choice and also what might be affected by the changing relations (Dodd, 2018b). The structural determinism assumed here is in the form of relational conditioning of choose-ables be-coming (i.e. visible or imaginable) so that, ultimately, choose-ables shape the potential ways in which a subject might 'be-have'. This makes reference back to the iceberg metaphor as depicted in Chapter 1, Section 1.3, Figure 1-2.

Developing the theme of relational conditions further, Morgan (1997; p373) states:

> "*Under appropriate conditions, certain explicate orders become likely, or possible, realizing the logic of the system*".

It is this final statement that is studied in greater depth throughout this thesis, using the nested orders of choice as the 'logic of the system'. The novelty lies in the centrality of the subject as the receiver of the realised logic of the system. What is decided and then becomes objectively evident as 'behaviour' is covered well in the literature; however, what might be being attended to (Dodd, 2018a) by whatever or whomever is on the receiving-end, and why (or why not), has not been covered formally and structurally in the literature to date. Morgan (1997; p227) states that: "unfortunately very little

[20] See https://www.edge.org/conversation/stuart_a_kauffman-beyond-reductionism-reinventing-the-sacred

research has as yet been conducted on this topic". Bateson (1972; 2002) presents an analysis of the pathology of purposefulness that points more evidentially to the lack of a 'logic of the system'; in particular, that the majority of the decision-making studies are lacking when it comes to structural awareness. The decision-making literature, and academic studies on decision-making, assume a given set of decision options without any reference to a broader changing context or any other kind of choice-forming structure. This thesis brings that logical, systemic 'structural awareness' to the fore as it develops a set of topologically-related orders of choice forming relational conditions to shape choose-ables in the form of potential 'affordances' for a subject's ways forward.

Affordance (Klugl, 2015) is an important concept in that choose-ables describe the subjective contextual nature of the opportunities for choice-making and the 'wiggle room' (Bradshaw et al, 2004) afforded to the subject by their context, for their consideration of potential ways forward. Affordances are defined as properties of the context taken relative to, and subject to, any person or agent (Wells, 2002); however, as such, they do not explicitly define a subject's constraints or desires, being more about the perception of the environment inviting different kinds of responses. Affordances do pertain to the context and are relative to and subject to what that context offers, opens-up or closes off, perceptually as well as operationally for that subject in their current circumstances. This does not explicitly include the agent's capabilities in terms of what might be predicted to be probable outcomes of decisions, both of which further affect an agent's ultimate choice of option. An agent's appreciation of how difficult or impossible it is to predict is related to their ability to look at context. This ability to look out into context is referred to as 'contextual intelligence' (Khanna, 2014). That difficulty or impossibility to predict tends to increase with complexity and intricacy of context.

Figure 2-2 illustrates the concept of affordance in terms of the scope of choose-ables (Dodd, 2018b) as an emergent property of three 'affording' factors:

- A subject's degree of conformance, adherence to laws, rules, customs, etc;
- A subject's degree of will and motivation (i.e. drive to extend or limit choices given subjective needs and context); and
- Means available and accessible (i.e. feasibility check on choose-ables based on capability).

All of these combine with the subject and their relationship with their context to shape the affordance for that subject, in terms of choose-able ways forward. As such, they emerge as that subject's scope of choose-ables. The orders of choice framework takes the concept of affordance and scope of choose-ables into areas of context that are not just about being active and predictive. The framework formalises the ways in which a subject might be conditioning their context as well as how they might be perceiving it.

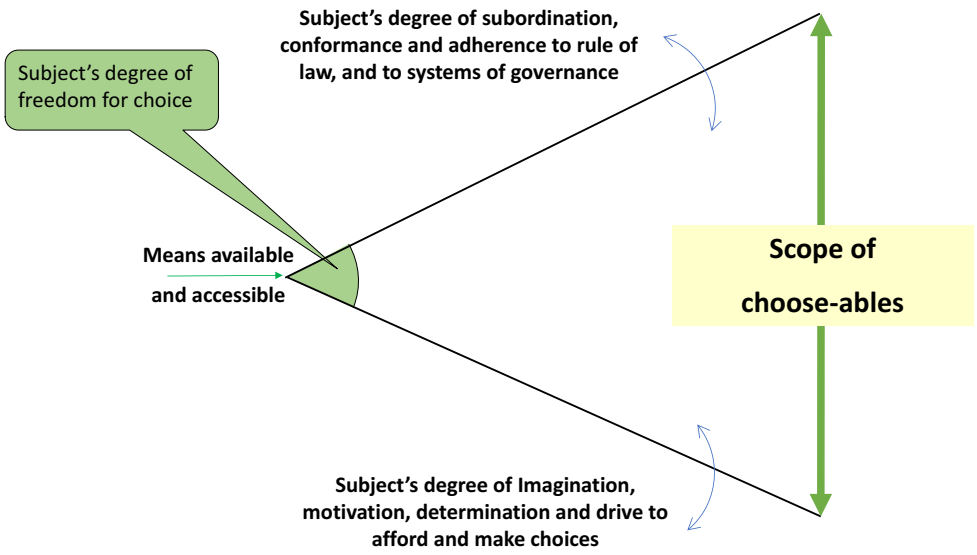

Figure 2-2: A subject's emergent scope of choose-ables (Source: Author)

All of this becomes increasingly relevant with the development of artificial intelligence agents and the questions around autonomy. Boden (1996) presents a typology for different degrees and gradations of autonomy and identifies three dimensions according to which an agent's autonomy can be judged:

- The extent to which an agent's responses to external stimuli are purely reactive or mediated by inner mechanisms being partly dependent on an agent's history of sensory input and/or internal state.
- The extent to which an agent's inner control mechanisms have been self-generated or self-organised rather than been externally imposed.
- The extent to which a system's inner directing mechanisms can be reflected upon and/or selectively modified, by the individual concerned.

Boden's (1996) third dimension adopts a different kind of subjective language and is about a subject's capacity for modification or adaptation based on reflections coming from contextual dynamics, which are being shaped according to the nature and scope of their choose-ables. Boden's (1996) third dimension is taken further and, importantly for this thesis, relates degrees of agent autonomy to perception and action in 'embodied agents' (Vernon et al, 2015; p19):

> "*The perceptions and actions are mutually dependent because they are both modulated by the system—globally-determined—through downward causation. Together they form a process of mutual perturbation of the agent and environment in which it is embedded, i.e., structural coupling, that facilitates both constitutive and behavioral autonomy. It remains as a significant research challenge to uncover the specific mechanisms by which circular causality and allostasis arise in natural agents and how—and to what degree—they might be replicated in artificial systems*."

The use of the term downward causation tends to set this work in a top-down frame of causal links; however, the reference to circular causality then hints at a need for a more holistic nested framework, which is what the orders of choice framework offers and, being relational, it is less about causality. Allostasis permits adaptive regulation, according to Sterling (2012) when studying stability through change, which accounts for both internal needs and external pressures (or opportunities). Therefore, allostasis is concerned with prospectively adapting to change (and to variation in change) in order to achieve the goal of stability in the face of uncertain circumstances. This relates directly to the variative and prospective orders of choice as captured by the framework, and the form of time itself becomes part of the nature of the choose-ables.

Essentially, this thesis is concerned with the subjective nature of what is being created (through being imagined and deemed possible) by a subject in the form of choose-ables as related to the subjective nature of what is being received, attended-to, noticed and comprehended; and to what degree, how and why. This then opens up a relatively unexplored area of research based around the sensing and sense-making 'of the beholder'. This points to a fundamental principle of invariance that is shaping a subject's choose-ables (e.g. 'adjacent-possibles' for adaptation) within their order of choice, which is further shaped by that subject's delineation of self within context; also, choose-ables shape the open-ness or closed-ness of senses, and of the frames of reference used for sense-making.

The principle of invariance and its generality (Quigg, 2019) that is being pursued in this thesis is a mathematical-physics principle of invariance (Noether, 1918; 2011). The proposition is that it can be extended to aspects of subjective choice. This is appropriate because the catastrophe models depend on a principle of 'settling' to find local or global minima. Quigg (2019) also discusses the importance of continuing on through mathematical derivatives to explore the nature of time in theories of invariance. The orders of choice see mathematical derivatives more as differentiation and integration by choice rather than time; with time taking on different forms across the different natures of choose-ables. Shackle (1954) addresses forms of time, as they link to subjectivity, by suggesting that there is no possibility that moments of time (i.e. Kairos) can be drawn together in chronological form (i.e. Chronos). Shackle (1954) holds that any connections between moments in time tend to be 'theoretical' because things happening according to such time are 'brought about' by the subject's imaginative potential (Knudsen, 2000). The framework for orders of choice adds to this by suggesting that connections between moments in time relate to that subject's open-ness or closed-ness to imaginative potential. Indeed, if a subject's motivation or drive to use imaginative potential is dulled or not present, then this will be evident in the nature and scope of their choose-ables.

Morgan (1997; p371) points out: "Bohm invites us to envisage the universe as an unfolding set of relations". This suggests a kind of generative depth of changing relations that might run through aspects of a subject's choices and, in particular, of choice-making. This thesis proposes that it is useful to focus on those changing relations that might shape choose-ables, such that the relational shape-changing creates the potential (at varying orders of choice) for emergent observable forms. The orders of choice are proposed as a useful classification scheme that may then provide a more formal mathematical basis for other levels-based schemes. The various schemes of orders, or levels, covered in the review of the literature have emerged from a variety of disciplines and domains, including General Systems Theory, human and organisational developmental studies, and anthropology.

The thesis does not take the matter of a subject's potential any further and so does not make any propositions about any specific resultant behaviours that may come about. Morgan (1997) goes on to explain further the relationship[21] between implicate order and explicate order: "the forms realised in the explicate order …. are *always* regarded as dependent on deeper forces within the implicate order". It is important to note the stress added here to the word "always" because it points to the need to develop a framework for understanding the structural logic of implicate order that underlies explicate order. So, the theory-based framework needs to be able to account for the realised explicate order, in terms of what might be being brought into visible or audible form, not necessarily being noticed, attended-to or comprehended by the subject due to the nature and scope of the choose-ables.

In summary, the research gap being addressed is characterised according to the four key aspects of need for a formal analytical framework that is holistic, subjective, positional and theory-based:

- A nested holistic framework that describes how deep implicate order extends into subjective context, on which the imaginative potential and the deeming possible of a subject's different natures of choose-ables depends.
- A formal way to address subjective choice-making and choose-ables rather than objective decision-making and choice selection.
- A way to appreciate 'where a subject is' in terms of their choice-making potential as it relates to their degree of open-ness (or closed-ness) of sensing and sense-making.
- Rigorous theory-based framework for choice-making and scope of choose-ables.

These are shown charted against the publication path in Chapter 5, Section 5.7, Figure 5-1.

2.6. Catastrophe models for describing orders of choice

This section introduces the mathematics and outlines the orders of choice framework to show that it addresses the research gap and also provides a way to approach and answer the research question. It is not necessary to work through any detailed mathematics as it is the interpretation of the Catastrophe models that is relevant to orders of choice; in particular, their descriptive power, with regard to the 'choice' characteristics as represented by the parameters in each model, along with their topology in relation to the nature and scope of choose-ables. The Catastrophe models are based on a principle of finding invariant regions or 'settling' points of minimum discomfort, which are represented by 'output' variables 'x' and 'y' in the equations in Table 2-4. It should be noted here that the traditional use of these models is to address system 'outputs', such as observable system 'chosen' behaviour. Given that this thesis is about choice-making and choose-ables, the variables in the Catastrophe models are being used to represent choice potential (i.e. choose-ables) rather than

[21] Note that the word 'relationship' is used when it is a link *between* things or people; rather than relation that refers to the relational nature of the order of choice (e.g. what might be forming distinctions).

outputs of choices selected by a subject. This is a subtle but important distinction because herein lies an important aspect of the novelty in this PhD study.

In line with the founding topological theory of Catastrophe Theory (Thom, 1975; Zeeman, 1977), seven orders of choice are presented to align with the seven catastrophe models as in Table 2-4.

Table 2-4: Catastrophe models (Zeeman, 1977)

		Rank	Co-dimension	Potential function
Cuspoid models	Fold	1	1	$\frac{1}{3}x^3 - ax$
	Cusp	1	2	$\frac{1}{4}x^4 - ax - \frac{1}{2}bx^2$
	Swallowtail	1	3	$\frac{1}{5}x^5 - ax - \frac{1}{2}bx^2 - \frac{1}{3}cx^3$
	Butterfly	1	4	$\frac{1}{6}x^6 - ax - \frac{1}{2}bx^2 - \frac{1}{3}cx^3 - \frac{1}{4}dx^4$
Umbilic models	Hyperbolic	2	3	$x^3 + y^3 + ax + by + cxy$
	Elliptic	2	3	$x^3 - xy^2 + ax + by + c(x^2 + y^2)$
	Parabolic	2	4	$x^2y + y^4 + ax + by + cx^2 + dy^2$

The cuspoids are based on a single 'output' variable (*x*) and each builds from the previous one through a process of integration of the potential[22] function, which is then differentiated, with respect to *x,* to give minima acting as stable attractors, with respect to the singular *x*. The umbilics are co-rank 2 meaning that they are based on two variables (*x* and *y* as cxy in hyperbolic); (*x* or *y* as $c(x^2 + y^2)$ in elliptic). In general, the potentials with exponents of odd number (i.e. fold, swallowtail, elliptic) tend to be transient in nature. The stable forms found in nature[23] tend to be described by the cusp and parabolic, being the only two equations containing the valuative parameter 'd'. The hyperbolic is described by Thom (1975) as a forming and breaking wave crest[24], so tends to have dynamics that are transient through the elliptic, which is described as a spike. The parabolic is described as a mushroom.

The following sub-sections describe each of the seven Catastrophe models, with an explanation of their relevance to the seven-fold orders of choice framework.

Threshold order of choice: Fold Catastrophe

Choice at this order can be defined in terms of ways of applying thresholding for any threshold-driven response towards or away from what is often labelled as a 'norm' (or normative threshold). Choose-ables are about a subject's ways of thresholding in terms of, for example, a machine-like step-function at one end of a choose-ables spectrum to a more nuanced settling or resolving into less discomforting

[22] It is important to note here that these are *potential* functions and the main point of this thesis is that it is a study of subjective potential for choice-making rather than being about objective decision-making.
[23] This extends from biological forms of nature to stable socio-political forms.
[24] See Figure 5.18 in Thom (1975; p79)

ways according to a subject's and others' felt degrees of proximity to their working thresholds. So, choose-ables tend to be based on a subject's ways of coming to their threshold-related needs to lower discomfort and also ways of expressing their deemed ease or feasibility. Alternatively, and less obviously, choose-ables could involve ways to adapt their threshold(s).

The thresholding within this order of choice is described by the fold catastrophe. In Table 2-4 the parameter 'a' is called 'the normal factor'. It defines regions of stable comfort for any responsive subject. This does not mean that these 'basins' of stability are static or fixed. The normal factor represents the degree of deviation (i.e. being sensed or felt as a subject's degree of discomfort) between a threshold-norm and a subject's felt state. Essentially then, it is a distance measure of deviation between a norm position and a felt position (e.g. current state of a system, perceived state of affairs, etc). A subject's choose-ables here are related to the natures of their tolerance thresholds. In mechanical terms, the norm would be seen as purposive in nature (Waring, 1996) and the felt position would be as determined by, usually externally set, system-indicators; as such, when the indications are that the current position has deviated beyond any tolerance thresholds then new responsive choose-ables may need to come into play. This then opens-up questions about a subject's ways of sensing and sense-making that may shift or bias their indications of position in relation to thresholds.

So, this order of choice lies at the heart of understanding different natures of responsiveness (e.g. procedural adjustment where a choose-able would form in response to basic levels of discomfort). For example, a valve that can only open or close according to a normative threshold, as the indicated state moves away from that threshold. The other less obvious response, as a choose-able, at this order of choice is the adaptation of the threshold; for example, a governance system making an adjustment to the open/close threshold for a valve; and, potentially less obviously, opening-up or closing-off of sensors (e.g. receptors) to sharpen or block out, respectively, any sense of discomfort. So, a subject could make a choice to block out certain signals (e.g. selectively closing receptors); or, re-interpret the signals to keep their circumstances seeming to be more settled and comfortable. The threshold order of choice tends to be relevant where efficiency of operation is paramount. Where, say, due to increasing need for efficiency, managerial systems have become procedural in nature, there can be instances of choose-ables based in this order of choice. For example, setting of targets to drive for more responsive actions towards higher levels of performance.

Variative order of choice: Cusp Catastrophe

Choice at this order involves a subject's ways of sensing and engaging with variability, uncertainty or ambiguity. Choose-ables stem from the strength of a subject's need for certainty in their current position and/or the setting of their normative thresholds. Any affordance of confusion tends to blur a subject's sensing of deviation, as described by the threshold order above, and so any deductive need for responsive choices is now not so clearly presented or worked out. A physiological example would be in normo-thermia when a subject's sensing of temperature has been disturbed in some way, then some threshold-based choose-ables may be closed-off due to internal uncertainty. One tendency here is for choose-ables to be about delaying choice until the degree of uncertainty or confusion might be

reduced by the subject. Choose-ables may come into play that restrict a subject's ways of sense-making; for example, using simplified models to 'clear-up' any uncertainties.

If neither of these (e.g. closing of 'eyes or minds') are imaginable or deemed possible by a subject, and if the degree of discomfort being felt is becoming critical for the subject, then the scope of the choose-ables tends to become more polarised. This gives potential for discontinuous responses, whose stability, for that subject, would be experienced as a hysteresis loop (e.g. anorexia-nervosa (Zeeman, 1977; pp33-52)). So, as a subject's sensed uncertainty or felt confusion increases and the sense of discomfort remains high, the choose-ables tend to bifurcate towards the more extreme ends of the choice spectrum[25] (e.g. hypo- or hyper-response choose-ables). Such discontinuous, heightened response loops are commonplace in biological systems. In the case of the 'fight-flight' phenomenon, a subject feels to be in a position far from their comfort-threshold yet that position is being sensed as far from having the needed certainty. The choose-ables then reduce to two, more extreme, choose-ables, resulting in observed fight-flight behaviours.

The bi-polarity and discontinuity within the variative order of choice is described by the cusp catastrophe model. It tends to be applicable to understanding the dynamics of choice-making when looking at organisation as organism, as it relates generally to homeostatic discomforts[26] leading often to bipolar forms of stability (e.g. fight or flight). Choose-ables are concerned with a subject's comfort (or otherwise) with dealing with uncertainty or variability being sensed in their immediate context. The implications and linkages to other orders of choice here are important and will be addressed in due course.

In Table 2-4 for the cusp, there is the introduction of a parameter 'b' which is called 'the splitting factor'. Zeeman (1997) illustrates the splitting factor using a subject's choices when operating in what might be being seen as being in a 'bull' or 'bear' market. A subject's choices would be made according to that subject's preference, say, for using a linear spreadsheet way of modelling variability or being open-to-context. A change in market variability would be sensed and interpreted differently by the different preference types according to their different variative choose-ables. The resultant market behaviour would depend on the relative changing mix of the different preference types. Zeeman (1977) goes on to note that Thompson et al (1990)[27] find similar economic cycles amongst New Guinea tribesmen.

Prospective order of choice: Swallowtail Catastrophe

At this prospective order of choice, the nature of the dynamic itself becomes enfolded into the choice-making landscape because the choose-ables are about ways to run things forward in time. The choice-making landscape is now becoming difficult to describe because it involves the passage of time and choose-ables relating to this passage of time are inherent in the concept of adaptation and beliefs

[25] These are regions of choice where the uncertainty or confusion can be removed or ignored by the subject or rendered irrelevant by the extremity of the choice. The scope of the choose-ables, as in the normative case, remains imaginable but are being deemed impossible as the subject occludes all bar the extreme choose-ables.
[26] This leads into an allostatic sense of discomfort when uncertainty needs to be engaged with in order to address ways of looking forward in time (see Prospective order of choice).
[27] Thompson et al (1990) refer the cusp catastrophe to the stable cycles of pig-exchange.

about the future[28]. Essentially, this order of choice is about ways of tracing what has been sensed and interpreted previously, through into the present and on into the future. An example of discomfort within this order of choice is a move from a circumstance where a subject is projecting based on past trends, towards that subject being called upon to more openly imagine a range of different possible futures. This choose-able extension is about moving that subject away from a world where cause-and–effect appears to be sound and workable, into a world where there is no place for such a predictable basis of 'change levers' and their measurable effects.

Here there is potential for imposition of a subject's beliefs about the future; depending on the forms that these 'beliefs' (e.g. as expectations or stated probabilities) take. There are choices forming at this order that are about what a subject might choose to believe, and on what basis; also, what a subject chooses as their beliefs about future, and then might impose on others, then what shapes that subject's ways of projecting into the future. This leads naturally into seeing the previous orders of choice being shaped according to any changes occurring in this prospective order of choice[29]; also, in turn, this order of choice being shaped by the nature of a subject's threshold and variative choose-ables; all in the context, still and yet, of the orders yet to be described. The variative choose-ables offer ways for a subject to mask or misinterpret their sensing of variability in order to stay within a manageable position. This then has implications within this prospective order of choice.

An illustrative example of a subject's need to maintain the nature of the dynamics to within their sense of comfort (e.g. of ongoing manageability and comprehensibility) is drawn from a recent Financial Times article[30] about the ways in which economic forecasters are tuning down the degree of volatility in the financial markets. The prospective order of the framework can be used to understand and appreciate subjects' ways of dealing with the allostatic discomfort being felt due to increasing levels of economic volatility. The prospective order of choice addresses a subject's need for market volatility to be maintained at a level that is commensurate with their long and short-term ways of forecasting; so, economists' are tuning down economic volatility, which is likened in the article to their selective deafness to wild and noisy extents of volatile sounds coming from their car engine.

Economics is based in Chronos-time and economic volatility is measured against chronological time-lines. So, it may be useful here also to refer to forms of time (Dodd and Markham, 2012) that then links to orders of agility (Dodd and Markham, 2013) as depicted in the illustrative frame of reference in Chapter 4, Section 4.7, Figure 4-1. As a subject's choose-ables move through the orders of choice they follow the centre-to-outwards trajectories, which are shown in Figure 4-1. As, and if, they do so, a subject's sensing is able to move from passive observation, to anticipation through to eventual creative sense-making and more imaginative choice-making. This is correlated with moving from Chronos-time to Kairos-time[31] (Jaques, 1982), where sensing and knowing depends on different forms

[28] This also depends on the ways in which time is being treated by a subject; or, ways in which time is imposing itself, or being imposed, on a subject.
[29] Choices made in the normative and variative orders have some kind of 'time-stamp' (even if only 'before' and 'after') but now there is a flexibility (of closed/open-ness) about how futures might be related to past or present.
[30] See "Are markets somehow broken?" https://on.ft.com/2wUmNEf (accessed 15 June 2019).
[31] Dodd and Markham (2012) discuss Jaques' (1982) Kairos according to a successive dimension of time as it embodies elements of value (i.e. assessment of 'success'), whilst Chronos relates more to an intentional dimension of time as it covers looking forward in time (i.e. short-term or long-term projections of intent).

of knowledge being used as frames of reference for sense-making; then affording a broadening appreciation of value leading to the valuative order of choice. If subjects are wedded to Chronos-time, then their recourse is to tune down their senses when rising volatility creates a sense of discomfort.

The prospective order of choice deals with choose-ables that are about a subject's ways of projecting into the future and it is described by the swallowtail catastrophe model. It tends to be applicable to understanding the dynamics of choice-making when looking at organisation as neuro-cybernetic, as it relates generally to minimising allostatic discomforts[32]. So, importantly, at the transition between the prospective and the valuative order of choice the form of time itself (e.g. chronos or kairos) becomes involved in the nature of the choose-ables. This is consistent with Jaques' (1982) work on forms of time (i.e. successive and intentional) and also Stamp's (1990) levels where the transition between level 3 and level 4 involves capability to address timing as well as time. This transition is also where the ontological position becomes choose-able. For instance, if holding to cause-effect is important to a subject's sense of comfort then a realist position and an objective scientific method position matters. If a broader set of perspectives matters then an interpretivist position is more apt; here knowledge will tend to also broaden out into a more conjectural approach to knowledge (e.g. metis).

Valuative order of choice: Butterfly Catastrophe

Choice at this order is about a subject's concept of value. Choices made in the previous orders will have been influenced by a subjectively-held concept of value; that is 'what matters' to a subject and what is deemed to be important to hold on to (e.g. adhering to or preserving principles or making changes to those defined principles). At the previous inner orders of choice, limits to choose-ables are seen in terms of feasibility, and inherent discomfort. As such, valuative choose-ables within this order are generally adopted and can then be seen expressed (either purposefully or purposively) in terms of the setting of norms or thresholds in the threshold order[33]. They can also be expressed in the variative order of choice through a preference for certainty, and also in the prospective order of choice through a preference for straightforward extrapolation of trends to predict the future.

So, this order of choice is pivotal to the other orders. What is being held to or conjectured by a subject in the previous three orders is now understood to be dependent on concepts of value, whose degree of adaptability is determined by valuative choose-ables. This valuative order is also a focus for what might be opened-up, or closed-down, in the sense of bounding self, defining other and subscription to divisiveness in the orders yet to be described[34].

Formally, the mark of this valuative order is a subject's recognition and appreciation of boundaries between choose-ables and not-choose-ables (at all orders, including order four), and is reflecting value-driven preferences as well as feasibility. As such, choose-ables are influenced by subjective

[32] One example is Post-Hospitalisation Syndrome (PHS) (Goldwater et al, 2018) that is thought to be based on evidence about allostasis and the deleterious effects of allostatic overload leading to PHS patients thinking forward in time about risks of further illness or even their own death.

[33] Such changes in norm impact on normative behaviour, which may be reinforced through conformity that then ripples back through into the other orders to establish more deeply-set values. So-called 'cultural norms' and Thompson's (2008) cultural preferences (or predispositions) would be an example of this.

[34] What self-boundary, self-other and divisive choose-ables achieve is made evident in the setting of values.

factors, characterised broadly as pertaining to value. The previous prospective order is already suggestive of such subjective preferences in terms of beliefs. The orders to follow can then be seen, at least in part, to be shaping 'where these values come from' and a subject's need to adhere to, or challenge, values (their own and others'). This order provides a commentary on the epistemological foundation of the previous orders, recognising the subjectivity as characterising what a subject takes to be information or knowledge that matters to them and is deemed to be worthy of their attention.

This valuative order relates through affordance to the adaptiveness of choose-ables within the previous orders. When, for any subject, different values come into contention or conflict (Dodd and Smith, 2013), there can be a choose-able dilemma about which set of values to adhere to. In terms of what may need to remain invariant, in a community sense, the choose-ables could be open to adopting a new perspective or a different way of valuing. So, not only might there be choices about concepts of value, there may also have been an added conflict and confusion about which set of values might be imaginable and also be deemed subjectively possible to adopt.

One set of values might be being imposed (e.g. institutional values or family values taking precedence over individual values) and the nature of the choice will be felt mostly, in terms of discomfort, by the choice-making subject when the imposed values are in direct conflict with their individual values[35]. Conversely, the choose-able could be one of moving from a value-in-conflict circumstance to one where values are felt to be in harmony; also, away from trying to adhere to different sets of values to having a consensus on a 'trade-able' or negotiable set of principles to live by.

It is this valuative order of choice that opens-up the areas where most of the anthropological work on choice resides, as in Dodd (2011) referring to Thompson's (2008) work. Here the choices can be seen to be being made in terms of moving away from single point solutions towards regions of resolution (e.g. typically compromise resolutions). This order of choice deals with choose-ables that are about a subject's ways of valuing and it is described by the butterfly catastrophe model. The beauty of the butterfly catastrophe model is in the 'pocket' that appears when a subject can appreciate their concept of value in relation to others' concepts of value, and which affords a way for compromise and resolution:

> "*There are three allowed values of the behavior in this region, one on the upper fold and one on the lower field, with the two intermediate folds inaccessible; then, one on the center fold. This extra allowed fold is called the pocket of compromise because it is a region of permissible behavior between the extremes."* (Poole, 1984; p308).

The seven publications take the theory only to this point based on the four cuspoid catastrophe models and so the following discussion can be presented purely as a suggested natural extension of the theory. There is very little in the academic literature that looks at the use of the umbilic catastrophe models in social studies. The discussion of the umbilics has been mainly based around natural and biological forms; indeed, the three umbilic models are called wave, hair (or spike) and mushroom respectively. The only source of detailed application to socio-political areas has been by Guastello (1995), who discusses empirical studies on organisational behaviour covering stress,

[35] Any social setting can be subject to the impact of these valuative-order choices; for instance, when a cultural 'tribe' or institution might be forced to impose their cultural values over those of the individual.

motivation, risk analysis, creative problem solving and organisational leadership challenges. Formal exploration of applications of the umbilic models, using the orders of choice framework, is an area recommended for further research in Chapter 5, Section 5.4.

Self-boundary order of choice: Hyperbolic Umbilic

Choice at this order is in terms of the nature of the self-boundary; in particular, choices about the ways that the boundary of self might be defined and determined (Lester, 2015). The self-boundary is a distinction (Spencer-Brown, 1969) between what refers to self and what refers to a subject's 'non-self'. This order of choice is with regards to choices being deemed acceptable in terms of the nature of this self-context boundary; for example, being a self-sealed, buffered or porous boundary. It matters not whether the subject is a person, a cell, a plant, a nation-state, a society, a religion, an institution, an organisation, etc, it is only the relational nature of the self-context boundary that is the focus of choose-ables at this order of choice. Isaac and O'Conner (1976) discuss this in terms of a dynamic relation that differentiates self and determines development of self. In literature[36], McGinn (2017) argues that Shakespeare is sceptical of the notion that the self is a constant, definite, singular thing or static essence. Instead, McGinn (2017; p6) suggests that, for Shakespeare, "the self is *interactive* and *theatrical*". Self is interactive in that it never makes sense to talk about the self in isolation; hence, making the choose-ables about self, a central reference point for a relational approach. Self is theatrical in the sense of drama and the unfolding of self in relation to a chosen context composed of other subjects. The self only becomes apparent through interaction and inter-relation. Drama Theory (Bennett et al, 2001), as discussed by Dodd (2018b; 2014), referenced in Dodd (2011), provides an interesting springboard for future work (see Chapter 5, Section 5.4). The self-boundary order of choice could be described by the hyperbolic umbilic, which now has a 'y' as well as an 'x' in the equation.

Self-other order of choice: Elliptic Umbilic

This order of choice is closely-related to the previous self-boundary order[37] (Thom, 1975), taking that self-boundary choice a step further into the definition of what, in relation to self, determines 'other'. So, the self-boundary order takes a view on choose-ables relating to imaginable and possible boundaries between what is self and non-self, whereas, the self-other order recognises the possibility of taking a different view of what constitutes 'an other' or 'the other', in relation to self; in particular, then the choose-ables refer to the ways in which a subject might distinguish forms of other in relation to self.

The self-context boundary distinction is more about choices being made relating to the extensive development or the intensive closing-off of self. At the self-other order of choice, the choose-ables are about how that self is able to imagine and deem possible ways to develop an extensive version of other in relation to self. An example of such a choose-able is where a subject feels able to choose to

[36] https://philosophicaldisquisitions.blogspot.com/2010/01/shakespeares-philosophy.html (accessed Jul 2019)
[37] Topologically speaking. fifth and sixth orders are umbilics of rank 2 (see Table 2-1).

treat[38] others as one's-self; alternatively, where a subject deems others to be unlike self, differentiating others as being foreigners or, with respect to value, seen as enemies or adversaries. The self-other order of choice could be described by an elliptic umbilic.

Divisive order of choice: Parabolic Umbilic

The divisive order of choice is seen in terms of choices relating to what form division takes, which is where the two previous orders of choice might be leading to (e.g. the subject's world being divided into friend or foe) and/or being conditioned by (e.g. self is differentiated through being 'in-group' or 'out-group' through a subject's world being strongly divided into 'us and them'). If there is a natural division or distinction into two forms (e.g. being *either* male or female), which is taken by the subject to be an inevitable setting (e.g. of existence and reproduction), then the nature of that division is taken into account, as such, when choice-making. It could be taken into account by letting it dominate, form boundaries, define values, etc. Alternatively, it could be taken into account by simply letting it be, by drawing from the natural strengths of both and by working across the natural divide to help the differences to merge and become integrated (e.g. having the choice to see people as people, and humanity as a whole, rather than as being male or female). So, choose-ables here could be seen in terms of ways of treating any natural or synthesised division; either by making choices to divide up their contextual 'world' in a particular way or by making choices to overcome divisions and have choose-ables that are open to uniting their 'world' across any divides.

The divisive order of choice could be described by a parabolic umbilic, which is descriptively referred to by Thom (1975) also as a mushroom or fungi. This introduces potentially useful imaginative ideas for thinking more metaphorically about the emergence of observable mushrooms when conditions within the communication underlay are such that fruiting becomes a choice. Also, with respect to the divisive order, the question of sexual distinction in fungi is central to their reproduction and potential fruiting emergence, because fungi do not tend to reproduce sexually, and those that do are thought to be isogamous[39].

Taken as a whole, the mathematics of the catastrophe models embody the natures of the choose-ables within the orders of choice framework where the variables 'x' and 'y' represent the choices open to a subject given where they are in terms of their choice potential. Use of the catastrophe models addresses the research gap by providing a formal theory-based framework to address 'where subjects are' in terms of their potential for choice-making that extends into subjective context, on which the subject's imaginative potential and the deeming possible of choose-ables depends. The theory-based framework is also able to account for the potential effects of a subject's positioning in terms of what might not be being sensed, noticed, attended-to or internalised by the subject due to the nature and scope of the choose-ables. The framework helps to explain why.

[38] Here the 'other' could be described as being more or less dangerous to self (Matzinger, 2002) or even to be seen as 'things' (as in 'Human Resources') but they are not deemed to be foreign and potential threats to self.
[39] In biology, isogamy is a condition in which the sexual cells, or gametes, are of the same form and size and are usually indistinguishable from each other; e.g. through not being identified as being either male or female.

2.7. Illustrative uses of orders of choice for insights into choice-making

The orders of choice framework has many possible uses, acting as a formal systemic structure for describing any subject's 'choice potential'; both in terms of their scope of choose-ables and also the natures of their choose-ables. The most natural areas of application are those based on a subject's ways of self-determination, division or 'anti-ism'. For example, it could be used to reason about 'radicalisation', where the traditional focus tends to be on pre-determined, observable behavioural indicators of human subjects, either as individuals or as groups. The orders of choice framework, and its relativist stance, would take the study of radicalisation towards a more conceptual, relational view, which would include cellular processes of radicalisation (e.g. free radicals in biology). This would proffer questions about subject determination of self-boundary and self-other based on where the subject *is* in terms of their ways of sensing and making sense of their circumstances. This discussion of 'where a subject *is*' should then encourage reflection, on the part of those subjects trying to understand radicalisation[40], on the basis that they are also a subject, themselves being a part of the wider context. Then there can be firmer ground for more open discussion about concepts of value, that can be based more formally, relationally, and reflectively, in terms of preferences and choose-ables. This illustrative example shows the importance of establishing and understanding a subject's concept of value in determining where assumptions might be being made about where subjects stand. The next illustrative example develops this further by referring to recent findings relating to subjects' attitudes to choices about vaccination; in particular, studies that have addressed concepts of value in order to explain subjects' rationales for refusal to go for vaccination or for vaccine hesitancy.

An illustrative example: vaccination

The rising degree of anti-vaccine sentiment across many countries has become an issue for social concern (Amin et al, 2017). A subject's position on vaccination can be understood using the orders of choice framework, supported by Staged Appreciation (Dodd, 2018a), the first stage of which addresses 'where a subject is'. The orders of choice framework provides a structure against which to address this positioning of any subject. Working from the outside-in of Figure 1-1, or from bottom to top of Figure 1-2, both of which appear in Chapter 1, Section 1.3, the questions around a subject's positioning of themselves would be as illustrated in Table 2-5.

[40] It is questionable whether or not those naming the UK's "PREVENT" strategy reflected on such things when they named the strategy?

Table 2-5: Illustrative example of subject positioning against orders of choice.

Order of Choice	What it entails in terms of a subject's positioning
Divisive	Does the subject already position themselves as being either pro or anti vaccination? Or, are they remaining open to advice and discussion?
Self-other	Do they see themselves with others as part of a community or do they consider only issues of 'self', leaving others 'out of their equation'?
Self-boundary	Do they see themselves being protected through self being closed-off against risks and threats[41] from the outside context?
Valuative	How are they coming to their concepts of value? (see discussion below)
Prospective	In what ways might they think forward about the consequences of any of their actions; in particular their lack of action?
Variative	How might they be able to conceive and think through uncertainty and risk? (e.g. 'It is uncertain to me whether or not something bad might happen so I will not take a risk')
Threshold	In what ways might they be open to hearing stories and building their own narratives in order to set their subjective thresholds? (e.g. 'My friend told me this story and so I don't need to hear any more about vaccination as that has decided me')

Table 2-6 shows a small illustrative range of choose-ables for each of the seven orders of choice. Using the framework for any subject (with the guidance of the Dodd (2018a) Staged Appreciation check-list) it can be seen how any potential settings in some orders of choice can inform the closing-off or the opening-up of the scopes of choose-ables in the other orders. This would help those in government when they are considering policies; such as, compulsory vaccination where subjects' options for action will be singular. The potential ramifications can be envisaged across the orders of choice if the policy effectively closes subjects off from their preferred choose-ables.

[41] Vaccination is particularly emotive here because it is not only invasive (i.e. piercing the skin self-boundary) but it is also deliberately and consciously introducing a foreign threat agent into the self.

Table 2-6: Illustrative choose-ables for each order of choice.

Order of choice	**Illustrative Choose-ables**
Divisive	• Anti-vaccine stance • Pro-vaccine stance • Open to discussion
Self-other	• All forms of other are threat to self • Self-protection with others considered • Others are people too
Self-boundary	• Sealed boundary for total self-protection • Porous boundary for low-risk 'invasion' • Open to risk if wider benefits outweigh
Valuative	• Concepts of purity and liberty • Concepts of harm or danger • Concepts of fairness and community
Prospective	• Predicting based on extrapolation of local events • Looking at probable outcomes • Open to possibility listening to different projections
Variative	• Do not engage with anything uncertain • Work out the odds • Understand potential with respect to uncertainty
Threshold	• Set high and close-off sensing to avoid discomfort • Set adaptive threshold based on sensed indicators • Open to adapt as necessary for changing context

The recent study by Amin et al (2017) has been highlighted across the open literature[42] because of its focus on value-based rationales for vaccine hesitancy. The work has challenged the common rationale for pro-vaccination messaging, which is traditionally focused on values such as fairness or protection, aimed at changing attitudes that to date has tended to backfire (Nyhan et al, 2014). The work has taken a subject-focused approach to understand underlying concepts of value (i.e. values being placed on individual degrees of liberty and purity rather than fairness and protection):

> "*There were significant associations of purity and liberty with hesitancy, giving strong correlative support to a need for inclusion of broader themes in vaccine discussions*" Amin et al (2017; p1).

This discussion could be formally supported through application of the orders of choice framework, by addressing the reasons for subjects restricting their scope of choose-ables, where *their concept of value is centrally positioned*. The orders of choice framework would open-up questions about the ways in which subjects come to their concept of value, which would broaden and extend the investigations

[42] https://www.scientificamerican.com/article/how-to-understand-and-help-the-vaccine-doubters/

into anti-vaccine sentiment, moving the discussion on from the usual information-messaging approach. The results of the value-based study have been surprising to the vaccination-promoting community; surprise being a telling indicator that strongly-held messaging models of the individual may need to be re-visited and adapted. It is a reminder that such information-messaging campaigns tend to be being done *to* a 'target audience' rather than being done in consultation *with* people through a full and formal understanding of their orders of choice, choose-ables and state of open-ness of sensing and framing.

An associated study by Omer et al (2017) relates a subject's ways of sensing and making sense of their immediate context, to their beliefs and preferences, as playing a large part in their threshold-based choose-ables (i.e. their inclusion of 'not to vaccinate' in their response choose-ables). They make the point that much of the US population is resistant to facts that come from medical experts or scientists and that this makes any form of communication around vaccine-related information extremely challenging to think through and get right. The orders of choice framework offers a way to think through where such fact-resistant subjects stand and helps to provide some explanation to the vaccine-promoting community about why their messages might be falling on closed-ears and closed-minds. This points again to the centrality of the valuative order of choice based on understanding what matters to each subject in terms of their considerations around concept of value.

The next illustrative example extends the use of the orders of choice framework for the purpose of understanding the limitations of Artificial Intelligence (AI) agents in terms of their potential for choice-making.

Use when thinking about Artificial Intelligence agent autonomy

The orders of choice framework becomes particularly relevant as the world moves more towards a mixing of subjects in collaboration with each other; for example, people and organisations working with AI agents. There will be questions around limits of (and abdication of) agency, authority and accountability, so some kind of formal systemic structural logic is needed to address these questions. For example, when might it be acceptable (and according to whom, what, why?) to grant full agency and authority to AI agents over their human counterparts? In what contexts? What assumed capacity for imaginative potential might such AI agents be expected or required to have? What are the natures and extents of their sensing and sense-making frames of reference? How might these be shaped by the AI agent's nature and scope of choose-ables? What would be an AI agent's equivalent of a sense of systemic discomfort?

The development of autonomous AI agents articulates the issues relating to orders of choice and it appears that some kind of theoretical framework may be useful here. Ziemke (1998; p 13) states that:

> "*Behavioral autonomy should be considered a continuum, not an all-or-nothing property. That means, there are different degrees of autonomy, i.e. degrees to which an agent is in control of its behavior*."

Ziemke (1998) claims that agents with 'full behavioral autonomy' do not exist in nature because of the behavioural limits of physiology, or biases within innate instincts, reflexes, etc. Living creatures are

said to be subject to such limits and biases due to evolution and so the limits and biases are not under an individual subject's 'control'. So, in nature, subjects are deemed to be without behavioral autonomy. Ziemke (1998) suggests that such subjects are not considered to be intelligent and, as such would not be of interest to AI and associated areas of cognitive science.

The orders of choice framework, and the insights drawn from taking a subject's perspective, would suggest that the distinctions may not be so clear-cut. Indeed, there may need to be careful application of the systemic structural logic, based on the orders of choice framework, to understand the implications of making any such distinctions. In AI agent development, it is the developer that determines the nature and scope of the agent's choices, most probably without any reference to a framework for orders of choice or an acknowledgement or understanding of their concept of value. So, the orders of choice framework offers the study of autonomous AI agents a way of positioning an agent's autonomy in terms of the agent's capacity for conception of their context and their circumstances; also, importantly, relating to their capacity for sensing and making sense of such a subjective context and changing set of circumstances.

2.8. Summary discussion of the schemes relating to the orders of choice

This review of the literature covering the levels-based schemes shows that a nested theoretical framework based on the seven orders of choice provides a sound general basis for describing a subject's potential in terms of their choose-ables. The nested logic of the structure fulfils the need for a holistic framework that has long been a vision in General Systems Theory (Churchman, 1971; Bertalanffy, 1969), and as had been studied previously by academics and practitioners looking for a formal way to 'model' holistically (Smuts, 1926) and systemically (Angyal, 1941).

Superficially Stamp's (1990) first five levels of capability could be seen to align directly to Beer's (1995) system levels, although the VSM has an added nuance of a nested structure. The importance of the nested structure is that Beer's (1990) System 1 contains within it a smaller-scale version of the whole system. Stamp's (1990) levels of capability however do embody the nested-ness of capability, as at Level 1 capability (carefully noted to be where quality emerges) there is the potential for a subject to be aware and understand the natures and scopes of the other levels and to bring them into being.

This helps to make evident that the scope of the choose-ables has an impact on a subject's capacity to sense and make sense of their context. For example, if a subject operating within System 1 has the capability to embody the awareness and understanding of the other levels then their scope of choose-ables tends to be moderated accordingly. The nature of the choose-ables being conditioned by the higher-levels can either provide room for that subject to make choices (i.e. able to be based on their own judgement) or limit that subject to work with set procedures and practices. This is captured by Stamp's (1990; p19) "unless-cannot" sense of a nested framework where a person's capability is being moderated according to the capability within the holding organisation[43].

[43] See also: http://bioss.com/gillian-stamp/contexts-for-change/ (accessed October 2019)

So that the orders of choice can be related to ways of sensing and sense-making, a simple construct is presented and discussed. Figure 2-3 uses a 2-dimensional schematic of a subject's state of being with two sets of signals (signal 1 and signal 2) defining the subject's 'comfort-zone' threshold. The subject is sensing a gradual change through the two signal inputs that could be (being subjectively) predicted as moving (i.e. the graduated arrow) towards their discomfort threshold (i.e. the edge of the comfort-zone). A subject's choose-ables could range across any of these orders of choice:

- Allow sense of discomfort to increase and have a range of responses if deemed necessary;
- Block-out signal 1 (i.e. the source of discomfort) and dull the senses to avoid having to make responsive choices;
- Add noise to signals to confuse things; or, disbelieve the trajectory of the path;
- Re-assess boundary of comfort-zone (e.g. blur or open-up the boundary);
- Re-position or open-up the comfort-zone (e.g. extend for sake of 'greater good');
- Introduce other kinds of signal to re-balance sense of discomfort (e.g. by being alive to different, wider signals);
- Question why the two orthogonal signals determine discomfort.

Morgan's (1997) metaphors would suggest, for instance, that, if organised and working as a machine, a subject would be focused within the threshold order of choice with the remaining orders making up a conditional context, which may or may not be (being subjectively) registered or may not be accessible other than via the context-set conditions (e.g. setting the signals as indicators and fixing the thresholds). The read-across to Jaques' (1979) Level 1 is straightforward in this instance.

VSM could be used to diagnose what kinds of choose-ables are likely to be being addressed at each of the systems levels so that they are commensurate with the nature of the work, that is also commensurate with the degree of variety and challenge being attenuated from the environment. This is a tenet of the Jaques, Stamp and Isaac's (Jaques et al, 1978) levels of capability also. Assuming that any subject's capability is made up of their access to means, ways and will (Smith, 2006), the orders of choice framework provides a language with which to describe and formally order any subject's access to imaginative potential within and context without in terms of their means and ways. Smith's (2006) view is that a subject's will contributes exponentially to capability such that any resistance or attraction to eventual orders of choice for ways to go forward is driven by their concept of value. This framework, with focus on the valuative and divisive orders, now shows the central importance of will when coming to an understanding of motivation and capability.

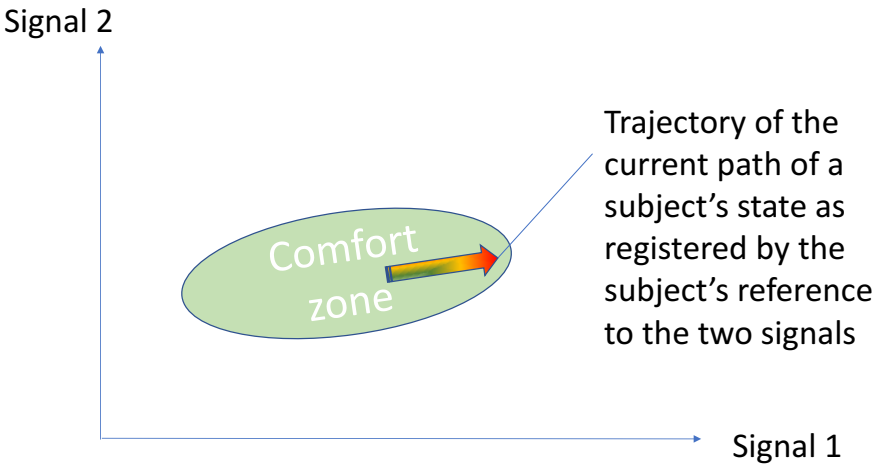

Figure 2-3: Simple schematic to illustrate a subject's orders of choice (Source: Author)

2.9. Completing the ring of choices

Each of the orders of choice is intrinsically inter-related to others through their nested form of reference. Change within one of the orders of choice shapes or re-forms other orders dependent on the degrees of freedom of choice[44] within those other orders of choice. Movement towards an operating unity, drawing strengths from natural differences within the divisive order of choice could, for example, be manifested through the re-forming of normative subjects to be "figures of grace" (Robinson, 2015; p 72) rather than figures of regulation and obedience or compliance.

Thompson's (2008; p144) Figure 9.2 illustrates a morphogenetic field and its projection onto a control space based on five cultural 'social solidarities':

> *"This three-dimensional surface depicts the simplest dynamical system. We could have "overhangs" (cusp catastrophes) along any of the four sides of this morphogenetic field, which could result in sudden discontinuous transitions straight from one corner to an adjacent one without there always being a transitional hermit state[45]….and the surface itself could be changing its shape over time."*

The similarities to Thom's (1975; p83) Figure 5.21 are striking; in particular, the importance of attractors (i.e. Thompson's (2008) social solidarities, referred to as structural stabilities by Thom) and

[44] Freedom of choice relates, through choose-ables, to open-ness/closed-ness of eyes, ears, hearts and minds.
[45] The hermit state is represented by an unstable saddle point.

the central unstable saddle points in both Thompson and Thom is marked. Thompson (2008) goes on to say:

> *"The import of all this, and the whole justification that cultural theory be developed in the language of dynamical systems, is that it enables us to see why it is that attractors and separatrices are arranged in this particular way…..it is only by setting it all out in dynamical systems terms that we can begin to understand what it is that cultural theory is saying."*

Thompson (2008) also has conceptual links (rather than directly referenced links) to Shackle (1976) through his discussions in the final chapters on surprise (with its organisational learning links to Emery and Trist (1965) due as much to what a subject is 'inside of' as much as what is inside it) and preferences (relating the formation of preferences to sense-making and discovery of preferences to relations).

Figure 2-4 provides a schematic map of the key reference areas and sources in the literature as they relate to each other; also, as they relate to the different aspects of choice: Self; Institution; Organisation; System and Subject. The shaded region depicts the area of interest for this PhD study with those concepts that lie outside the shaded region forming the important context. The lines show where the areas are connected explicitly in the literature. The two thicker dashed-lines are the novel connections being made by this thesis. The bringing together of Catastrophe Theory and Cultural Theory, and the adoption of a subjective stance as per Shackle's (1976) choose-ables, gives a useful new framework for describing a subject's potential in terms of orders of choice. In summary, Catastrophe Theory provides the structural logic for the natures of the choose-ables and Cultural Theory provides the structural logic for the scope of choose-ables.

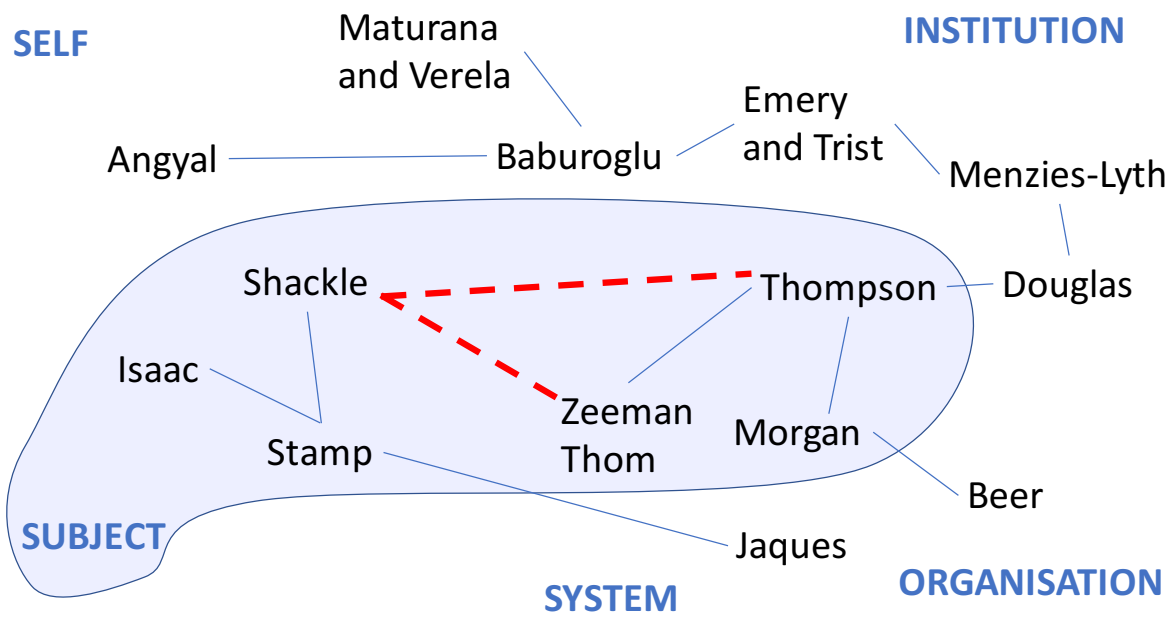

Figure 2-4: Literature area of interest and its context (Source: Author)

3. Methodology

This chapter discusses the methodological positions of the publications in terms of the epistemological approaches to knowledge as it is developed through the broadening of the study areas through the publications. It then explores the methodological challenge presented by this thesis in terms of the ontological conundrum presented by the orders of choice framework. Finally, it explains the ethical considerations made throughout the 15 years of the ongoing study covered by the publications and the thesis.

3.1. Introduction

The methodology used in this research study needs to be examined and questioned because the choose-ables-based approach to choice-making, which this study adopts, is subjective; and yet, because the study presents a theoretical framework, it is adopting an objective viewpoint. A most challenging concept throughout is that of the distinction being made between a subject's text and context as related to a subject's orders of choice. Espejo and Reyes (2011) discuss this methodological conundrum in terms of distinguishing a system from its environment. Their main concern is with moving from an operational view of systems to an organisational treatment of systems; however, there is a helpful discussion on the role of an observer. They make the point that the role of the observer is in determining the observer-object distinction which is consistent with this subject-based study. They go on to note that the position taken by an objectivist that the nature of the observer remains separate from their description of their observations needs to be replaced by "the description of the observations shall reveal the properties of the observer" (Espejo and Reyes, 2011; p7). This move away from a common 'objectivist and subjectivist' epistemological and ontological position towards a more *constructivist* approach, is where this study, which is focused on orders of choice. more naturally sits. The basis for the orders of choice is that any subject or community of sensory subjects will be coming to some kind of 'agreement' that temporarily, for the purposes of coordinating actions, allows them to share a reference space of distinctions that appear to them as if they had 'ontological reality'. The theoretical framework proposed through this study tends to move outside these limits and so this appearance of ontological reality may start to disappear or at least become troublesome to readers, as observers, as there may still be a need to retain access to ontological reality. An example that may help to illustrate this is set within the troublesome operational context of Bosnians in the former Yugoslavia[46] in the early 1990s, where there was a high proportion of ethnically-mixed families. Within the Bosnian families, the reality was that people are members of a family. The view of reality of those outside Bosnia was that people were seen to be either one ethnicity or the other, and whichever group others sensed that Bosnians belonged to became a matter of life and death. So, for such cases, a methodological approach should be able to manage the dilemma created by a need for an objective view of a situational reality (i.e. non-Bosnians identifying, judging and killing Bosnians) coupled with a need for a 'where people are' view of people's reality as it is being

[46] This example is an over-simplification of the complex situation (Gray, 1994) to make the illustrative point.

sensed, ascribed and played out within Bosnian ethnically-mixed families. Dodd (2018a) and the orders of choice framework help to position an analyst (as subject) who is carrying out a systems-based analysis, which is working to position the subjects of the objective analysis. It is this aspect of stand-points and systems analysis that is discussed next.

3.2. Cross domain application and the extension to the subjective

The various levels-based schemes covered in this study have emerged from a variety of disciplines and domains, including General Systems Theory (Bertalanffy, 1969), human developmental studies, organisational studies, biology and anthropology. As such, the orders of choice framework is based on a mix, across a range, of stand-points. Ontologically speaking then, it makes sense to consider a range of stand-points based on the nature of the subject. So, for instance, if the subject is an algorithm then the ontological position would be different from when the subject is a person or an institution.

The seven-order scheme for choice-making outlined in this thesis is proposed as a useful classification scheme that may then provide a more formal mathematical basis for those levels-based schemes; however, it is made more challenging to apply due to the synthesis of a subject (i.e. a subjective observer, sense-maker, and potential distinction-maker or distinction adopter) into the seven-order scheme for choice-making. There is no assumption made that an observer is somehow developing, ontologically and epistemologically, according to any kind of maturity-scale; for example, if the subject moves upwards and outwards in terms of the orders. At any time, the subject 'as observer' is subject to their choose-ables (i.e. ways forward that are imagine-able and deem-able possible) due to their sense of their context and associated distinctions, within and without.

The implicate/explicate idea is presented as a way to describe, for further study purposes, the implications for what lies beneath and between, in terms of what is then observable by a subject. Putting the two ideas together could, however, tempt some readers towards an assertion that the implicate form represents some 'deep and universal grammar'. The challenge for further research, therefore, is to work through illustrative examples in an attempt to show that in some particular domains the theoretical scheme holds according to a simple set of axioms, which could then in themselves be validated. Illustrative examples could be drawn from literature (e.g. Shakespeare plays) and socio-politics (e.g. recent voting choices) to act as use cases to show how the topological forms, within each order of choice, can describe differing potentials through changes in conditions (e.g. a company merger).

In seeking to employ these theoretical insights across domain boundaries (and in particular as part of a generalised ordered framework), there is a need for some caution and some methodological care. As discussed above, this is not a simple task because everything in the world of organisation (in Morgan's (1997) sense of the word) is metaphorical. In the case of the brain metaphor, it is doubly-metaphorical. Metaphors give us insights, but not every insight, which might then be suggested as theory, can be shown to be true or even useful. Methodological care and caution needs to be taken when transferring ideas from one metaphor to another.

Seeking to interpret a seven-order scheme from General Systems Theory by looking at the cultural and psychological factors pertaining to each level is a non-trivial exercise. It is potentially a useful (and possibly powerful) idea; however, there are methodological and philosophical complexities associated with this cross-domain work, and it is only possible at this stage to highlight some of the potential problems that have been worked around, rather than formally addressed.

3.3. Main areas of methodological concern

The main areas of methodological concern are as follows:

- Is the subjectivity, as is invested in a subject, merely 'another set of conditions', or is it a setting (Angyal, 1965) or conditioner that filters the explicate out of the implicate order(s)? The answer to this question is probably that it is both, which is not particularly satisfactory, methodologically speaking.
- If the 'logic' from General Systems Theory results in an objective landscape (that this thesis suggests is visualisable, or at least describable, when using Catastrophe Theory), is it true to say that the landscape 'experienced' by a subject is partly-obscured, potentially screened-off as a 'subjectified' version of an objective landscape? Or is it possible that the constructivist view of a subject's observations of their choice-landscape has no relation at all to the objectivist's view of an option-space? This is one of the most challenging issues.
- Might the 'subjectively-experienced' choice-landscape, as interpreted by a subject, contain options, choices or possibilities that may not exist at all on the objective landscape, or are the subject's choose-ables somehow being screened off by 'objective' conditions that the subject has failed to appreciate, or does not have the capacity to appreciate?
- Is it possible that the idea of 'implicate order plus conditions creates the explicate' could lead to an over-simplification? Given the social and personal complexities inherent in what is being called 'context', the process of any kind of representation of potential for the explicate from the implicate involves a multi-layered series of translations, into which subjective contextual factors need to be introduced.

All that can be said, therefore, is that the subjectivity being aimed for is a subject-based perspective on the characteristics implied by the different orders of any subject's choose-ables, as they pertain to their sensing and sense-making and to their choice-making. In such a frame of reference, a subject is open to different ways of distinguishing subject-self from context, where context is not the usual 'self-environment' or 'system-environment'. Context, subjectively speaking, is both within and without a subject, where the in-out boundary distinction is fluid, as subjected from other subjects' distinctions, and related to the subject's sensing, sense-making, and scope and nature of their choose-ables.

Therefore, this tends to settle the research philosophy away from a realist philosophy as it is exploring not only interpretation but also relative rationales for a subject's indications or interpretations. The position then seems to be more towards interpretivist, as shown at Table 3.1, which represents the orders of choice framework as a formal language through which to interpret and reason about a subject's potential.

Table 3-1: Characteristics of Interpretivism (Saunders, Lewis and Thornhill, 2016; p136)

Ontology	**Epistemology**	**Typical methods**
• Complex, rich • Socially constructed through culture and language • Multiple meanings, interpretations, 'realities' • Flux of processes, experiences, practices	• Theories and concepts too simplistic • Focus on narratives, stories, perceptions and interpretations • New understanding and worldviews as contribution	• Typically inductive. • Small illustrative samples, in-depth investigations, qualitative methods on analysis, but a range of data can then be interpreted

The methodological development path taken during the course of the research followed that of the orders of choice. Publication 1 presents the stance of a researcher collecting empirical data from a closed-form experiment with human subjects. The methodology for the experimentation and the findings was deductive with a clear 'human as observer' ontology of a presented situational reality. The objective analytical stance continued into Publication 2, which then shows the inductive application and development of theory with respect to the experimental findings. In Publication 3, decision theory is extended and combined with cultural theory, taking the inductive approach further so that the decision-making could be understood not only in terms of induction based on hierarchy but also by explaining interpretively the impact of hierarchical culture, resulting in a broader theory of choice.

The objective analytical stance was maintained to study orders of agility for Publication 4, exploring and explaining orders of change and forms of time. This then shifted noticably for Publication 5 where the emphasis was on adopting a more subjective stance in order to appreciate adaptive systems from different stakeholders' perspectives and to see systems of interest through different stakeholders' 'lenses'. The approach here was still in the realm of analysis but was presenting more subjective ways of analysing. In Publication 6, this was taken further and moved wholly into the subjective stance such that, what may have been seen as realist and interpretivist previously, was now constructivist. Publication 6 acknowledged that where subjects *are* in terms of their preferences, beliefs and choose-ables has implications for their scope of focus and interpretation of their circumstances. In Publication 7, an inductive approach was then taken to the subject of Publication 3 to formalise the links between Catastrophe Theory and Cultural Theory, through formal reference to the subjective concept of choose-ables. Overall, the research studies have taken an analytical stance throughout but have incrementally become more reflective in the effort to understand a more subjective perspective; addressing not only multiple perspectives (as in Publication 5) but also a deepening of what constitutes a subjective stance.

Ontologically, in Publication 1, the choice-agent is taken to be a rational decision-taker in the context of a demarcated Command and Control (C2) hierarchy, where higher-levels of command set the

strategic purpose for the lower-levels. At this stage, this did not take into account the inherent relationships in such a hierarchical setting, nor the ways in which 'the situation', as presented to the decision-takers, was divided into own-forces and enemy-forces. The value-base was taken to be one of military utility, other than to register that this would widen in terms of time-scale as the object of choice moved upwards through the C2 hierarchy. Forms of time are strictly chronological in the first two publications; subjective, successive 'kairos' time is implicit in Publication 3 and only begins to be explicitly studied in Publication 4, where the nature of time becomes part of the choose-able scope.

The nature of the choices being made then becomes more meaningful, as the orders of agility are framed in Publication 4. Then in Publication 6, an argument is made for a broadening of the analytical stance to consider 'where people are', ontologically, in terms of their ways of relating to, and engaging with, their contexts; epistemologically, in terms of ways in which they draw working knowledge from their contexts, in relation to themselves. Forms of knowledge are also discussed. The usefulness of choose-ables as a concept draws these two aspects together in Publication 7 where the scope of choose-ables shapes that drawing of knowledge and the nature of choose-ables shapes the ways in which choice-agents are engaging with their context. It is only in this thesis that the choose-ables extend to consider the ways in which a subject might be drawing distinctions within that context, which then has to be called 'a subject's circumstances'.

As the writing of the thesis progressed, it became clearer that a subjective standpoint forms the foundation for this on-going ontological approach, which has moved from being a critical realist perspective towards a relativist approach. The seven publications use terms such as 'situation' and 'environment', which are more objective, more realist forms of the potential scope of focus and interest for a decision-maker or sense-maker. This thesis moves away from the human decision-maker (or analyst) being the subject of the study to it being about any form of subject. Indeed, the subject emerges, through their orders of choice, from the distinctions being made by the subject about what constitutes their context. The more natural terms then are 'context' and 'circumstances', as related to a subject, which takes the ontological stance to relativist. Distinction of self, in relation to context and in relation to other (as discussed in this thesis), is based on a relational dynamic element that has 'subject' as one of the poles. This seems to be an appropriate final position.

Through the publications, the epistemological themes broaden in line with the ontological progression. The four types of knowledge are mentioned in Publication 3, as drawn from Dodd (2009), which sets out a conceptual framework for natures of choice, according to different types of decision role, related to types of knowledge, as shown at Table 3.2.

The rows in Table 3.2 refer to different decision-roles (e.g. C2 hierarchical levels) and the widening nature of the choose-ables. The columns represent different forms of knowledge, as might be acquired by different subjects in different ways and at different times. For instance, the forms of skill-based, teachable knowledge (i.e. *techne* and *episteme*) can be acquired as part of 'learning by doing' training or study through attending. The other forms of knowledge (i.e. *phronesis* and *metis*) are more the product of multiple strands of *subjective learning or adaptation,* working through what is being valued. So, the growth of knowledge in any subject may refer to subjective and relational 'histories'. Whilst Table 3.2 points in one way to a subject's capacity to engage with the *future*, it also points to the role of these subjective and contextual (or cultural) histories.

Table 3-2: Table of types of knowledge against decision-roles (source: Dodd, 2009)

Type of Knowledge **Role type**	**Techne** (e.g. technical or mechanical or procedural skill/know how)	**Episteme** (e.g. learning from watching others or from books/lessons)	**Phronesis** (e.g. learning what and why from real felt experience)	**Metis** (e.g. knowing others' ways of knowing and perspectives)
Shaping	Mechanisms for setting policy (e.g. rules of engagement)	Knowledge of others' key strengths and weaknesses	Feel for when to re-generate or remove policy boundaries	How to shape relationships for natural flow of operations
Decision-making	People skills Appropriate delegation of decision rights.	Knowledge of own capability & organisation Constraints	Understanding of situation as a whole – as felt. Principles	Ability to create conditions and to balance all aspects
Decision-taking	Estimate processes CoA selection	Operational knowledge and effects	Create effective options outside usual CoA	Plan robustness and consider 'cunning' plans
Operating	Skills & refresh Practical task Performance	Knowledge about operating procedures and ways of working	Self reflection Creation of response action based on past experience	Understanding minds of other operators and knowing their perspective.

This conceptual framework, therefore, helps to frame the epistemological broadening of this research as it moved more towards an understanding and appreciation of subjectively being more towards the top-section of Table 3.2 (i.e. involving subjective experience and reflection on different perspectives, including the subject's own).

3.4. Ethical Considerations

The ethics considerations over the course of the 15 years that this study has been researched have addressed the appropriateness of behaviour, principally as my behaviour as the researcher, as part of a research team and also leading research, to ensure that the rights, needs and respect of participants have been carefully considered throughout the research (Saunders et al, 2007). Such considerations cover any moral principles, and norms or standards of a researcher's behaviour, which must guide the researcher's choices about their own behaviour and relationships with others (Blumberg et al, 2005). This is a key tenet of reflective practice and in the specific case of this research study it checks to make sure that what has been preached is actually being practiced. The later publications did not involve any participants directly; however, the research has taken clear guidance from Cranfield University's Ethics Policy, which all research requires explicit application to the Ethics Committee (CURES). The primary data collection and exploitation that took place through the experimentation described in Publication 1, which was then taken into development of theory, followed then the previous version of MOD's Research Ethics Committee (MODREC) research ethics principles (now updated and laid down in JSP 536[47] (2016)) to protect participants from any potential physical, psychological or personal harm. The previous principles followed Kervin's (1992) checklist for carefully identifying and then mitigating any risks of potential first-person or third-party harm. There was therefore, strict adherence to ethical research practice and ethical MOD community practice at all stages of the research study to keep it safely within ethical restraints. More recently, reference has also been made to the Economic and Social Research Council's key principles of ethical research.[48]

3.5. Summary

In summary, although the methodological journey has developed from being initially analytical, and almost objectively empirical in nature, to then being subjectively interpretivist, the philosophical stance finally taken to be described as constructivist leading towards pragmatist because what is offered finally is a logical structure for describing and understanding any subject's potential for choice-making. This thesis has been written separately (i.e. not just as a synoptic chapter) in order to align the different philosophical stances as adopted and worked through in the seven publications within the portfolio.

[47] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/553276/JSP536_Part1.pdf (accessed August 2019).

[48] https://esrc.ukri.org/funding/guidance-for-applicants/research-ethics/our-core-principles/ (accessed September 2019)

4. The Publications

This chapter gives summarised details of the seven publications to lead into Chapter 5, which then shows how the publications provide ways to address the overarching research question:

> *From where might a subject's choose-ables emerge; and how might these choose-ables moderate, or be moderated by, that subject's sense-making and their focus of attention?*

Each of the seven publications is covered here in turn, in narrative order, with the key aspects of each paper extracted and presented to explain the narrative (see Section 4.2, Figure 4-6). The full versions of the publications are presented at Annex A with the corresponding contribution statements from the three co-authors.

4.1. Details of the seven publications (in narrative order, not in date order)

Set out below is a list of the references for each of the publications as they appear in the narrative:

1. Dodd L, Moffat J, Smith JQ, and Mathieson G (2004) Discontinuity in decision-making when objectives conflict: a military command decision case study, *International Symposium on Military Operational Research*, UK. http://ismor.cds.cranfield.ac.uk/21st-symposium-2004 (see also: Dodd L, Moffat J, Mathieson G and Smith JQ (2003) From simple prescriptive to complex descriptive models: an example from a recent command decision-making experiment. Proc. 8th *International Command & Control Research & Technology Symposium*, National Defense University, Washington.)
2. Dodd L and Smith J Q (2012) Devolving command decisions in complex operations, *Journal of the Operational Research Society*, 64:1, DOI: 10.1057/jors.2012.7
3. Dodd L (2011) A Theory of Choices: melding black swans, butterflies and swallowtails, *Proceedings of 8th International Conference on Complexity Science*, June, Boston, USA.
4. Dodd L and Markham G (2013) Orders of C2 agility and implications for information and decision-making, *International Command and Control Research Technology Symposium*, Institute of Defense Analysis, Virginia. CCRP Publications. https://apps.dtic.mil/dtic/tr/fulltext/u2/a587016.pdf
5. Dodd L and Alston A J (2009) Complex Adaptive and 'Inquiring' Systems Theory for Contemporary Military Operations: A Multi-perspective Approach, *The Cornwallis Group XIV: Analysis of Societal Conflict and Counter-insurgency*, Vienna. http://www.ismor.com/cornwallis/workshop_2009.shtml
6. Dodd L (2018a) Techne and techniques for engaging in a socially complex world, *Journal of the Operational Research Society*, 70:9, DOI: 10.1080/01605682.2018.1501461
7. Dodd L (2018b) Choice-making and choose-ables: making decision agents more human and choosy. *Euro Journal on Decision Processes*, Volume 7, Issue 1–2, pp. 101–115 https://doi.org/10.1007/s40070-018-0092-5

Now each of the publications is presented in turn.

Publication 1: From simple prescriptive to complex descriptive models: an example from a recent command decision experiment

Dodd L, Moffat J, Smith JQ, and Mathieson G (2004) Discontinuity in decision-making when objectives conflict: a military command decision case study, *International Symposium on Military Operational Research*, UK. http://ismor.cds.cranfield.ac.uk/21st-symposium-2004. Co-authored by Prof Jim Moffat, Prof Jim Smith, and Graham Mathieson (now sadly deceased).

Publication 1 describes an initial set of decision experiments with 24 senior military commanders. My work involved developing agent-based models to explore how subjects might transform observable situational data through interpretive indicators (or sense-making constructs) into course of action assessment and selection. The key transfer function for the agents (Dodd and Moffat, 2001) was driven by (a minimum of) two parameters, such that the function changes its shape (and influence) as the decision-agent's context changes. A typical example of such a functional change is when a local tactical decision might be seen by the tactical commander to be more global in its potential impact; conversely, functions would tighten when pressure is being put on a tactical commander to 'get it right'. The experimental results show that splitting factors (as for the cusp catastrophe in Chapter 2, Section 2.6, Table 2-4) can be derived from the subjective nature of the situation assessment, as moderated by the subject's preferences, training, experience and personal history. Dodd et al (2003) includes a further set of factors that drive the command decision process based on non-linear utility theory as developed by Smith et al (1981). The underlying theory makes three assumptions about the command-decision process:

1. There is uncertainty in belief about future outcomes;
2. Losses may result from any decision (or any lack of decision);
3. The overall desire is to minimise the likelihood of losses (or maximise potential gain/utility).

Essentially, the two functions of belief and outcome-based loss combine to give a believed likelihood of loss function; and, when this is minimised, a cusp catastrophe decision surface emerges. The experimental data helped to establish the relationships between utility/loss, uncertainty, beliefs, constraint formulation, and their effects on the subject's selection of Course of Action (CoA). At this stage of model development, there was no extension into subjective choice-making as the agents were purposive and had to be given their range of decision options with associated potential outcomes within the bounded context of combat mission.

Non-linear utility theory (Smith at al, 1981) assumes that any belief 'universe' can be formally described in terms of a triple of Utility-values (U), Decision-space (D) and Beliefs (B), respectively. Such triples may drive the CoA selection but should be evaluated and analysed within the context of the triples pertaining to the command levels immediately above and below that of the decision-maker (or least to the best of their interpretation and understanding). This leads the theory towards the butterfly catastrophe model (see Chapter 2, Section 2.6, Table 2-4). Consequently, there was a large degree of variability in the selected courses of action across the 24 participants in the experiment, despite all being given exactly the same situational briefing information. The paths taken in their pattern-

matching could be described formally, if it were possible to quantify the triples for each decision-maker. Their triple would effectively define their choice landscape within which their pattern-matching could be modelled, or at least theorised. The only way at the time of the experiment to establish the values for the triples was to ask participants to post-rationalise their decision-making. There was no formal systemic structure against which to rationalise the results of the experiment; hence the need for research into orders of choice and the novel links that needed to be made between Catastrophe Theory (Smith et al, 1981) and Shackle's (1976) three inter-related functions of focus, belief and preference.

The command decision experiment was based on Recognition-Primed Decision-making (RPD) (Klein, 1997) that consists of three phases: situation recognition, serial course of action evaluation and mental simulation. Serial course of action evaluation is undertaken only if the first 'natural' CoA is rejected. Mental simulation is the process used to serially evaluate actions if CoA evaluation is necessary. It is this aspect of mental simulation that is explored further in this thesis referring to the swallowtail catastrophe model (see Chapter 2, Section 2.6, Table 2-4). A key feature of RPD is the idea that decision-makers do not assess a situation using the objective information presented to them. Rather, they recognise the situation by pattern-matching the situational cues and indicators, using previous 'frames' from past experiences. This pre-learned knowledge shapes the way the decision-maker perceives the situation presented and provides the starting point for CoA generation and their choice-making.

The broader implications of RPD for choice-making are important to note because if experience is dominating, then the decision-maker's choose-ables will tend to be framed according to known, practiced and preferred choices. In further studies with Bomb Disposal operators (Sirett and Dodd, 2007), the experts termed these 'favoured' choose-ables as potentially being "fatal baggage" because they might frame their interpretation of the situation in ways known by their adversaries, and so situations may be set-up that could then blinker their sensing and bias their sense-making. This finding led my research to develop open-eyes/open-mind concept for Staged Appreciation.

The RPD game was designed to measure the predisposition of participants in a situation in which they should be experts, by requiring them to make a rapid determination of a CoA in the face of an ambiguous tactical situation. The ambiguity of the situation report was designed to give them some room for choosing different courses of action so that their pre-dispositions were allowed to surface as variations in choice. The RPD experimental game results provided a context within which to define the utility (or loss) values, the constraint 'landscape' and the beliefs about future outcome, all of which are subjective. Indeed, it appears that the extent to which each is considered in the pattern-matching process appears to play a strong role in the CoA selection. The other key feature that accounted for the groupings around selected CoAs, was the 'self-defining' regimental family of the 24 experienced military subjects taking part in the RPD game. This suggested that choice-making and then decision-making is affected not only by the nature of previous experience but also by personal, professional preferences, following their regimental culture and self-determination.

Publication 1 recommends that in order to capture these deeper aspects of the human decision-making process, there is a need to visualise a choice landscape whose contours are defined by the

subjective evaluation of 'potential losses' of moving over the landscape. These choice landscapes are wholly subjective and they change as the decision-maker's 'world' changes over time. The experimental results illustrated these points, showing that the move towards complex, less prescriptive agent-based models will increase the need for more subjective experimentation. The challenge then is how to capture this deeper representation of human decision-making in a way that could be useful for quantitative modelling. This challenge still remains and leads to a proposition in this thesis that quantitative agent-based modelling will not (and possibly cannot) capture the deeper subjective representations due to the necessary bounding conditions for encoding of agent-based decisions. However, it may be possible to develop descriptive frameworks that capture the nested nature of choice-making that can then inform agent-based modelling of human decision-making. It is this nested nature of choice-making that future publications develop and this thesis addresses.

The contribution of Publication 1 is the finding that subjective preferences tend to shape a subject's choices and that they in turn tend to impact on a subject's sensing, focus of attention and interest, and also their frames of reference for situational sense-making.

Publication 2: Devolving Command Decisions in Complex Operations

Dodd L and Smith J Q (2012) Devolving command decisions in complex operations, *Journal of the Operational Research Society*, 64:1, DOI: 10.1057/jors.2012.7

Publication 2 stands as the first stage in the development of the application of Catastrophe Theory models to decision-making in complex operations. It uses the mathematics of the cusp catastrophe, based on maximising the likelihood of conflicting utilities; however, its key point of discussion is the implications for decision-making when there are conflicting objectives in a military command chain. This work builds on Publication 1 (Dodd et al, 2004), which describes the previous research in decision-making under uncertainty and conflicting objectives. The RPD experimental data were used to demonstrate how multi-attribute utility theory (based on a cusp catastrophe model) could be used to represent and understand the effects of uncertainty and conflicting objectives on a particular commander's choices.

The paper's context is contemporary military endeavours, in which the Command and Control (C2) arrangements generally aim to ensure an appropriate regulation of command-decision-making so that decision-makers are able to act coherently in a way that is consistent with the overall set of commanders' intents and objectives. If the nature of the unfolding situation is such that it throws up unforeseen incidents for subordinate tactical commanders to deal with, then they may have to consider options that go outside, and may conflict with, the strategic command options. For example, this would occur when a likely outcome viewed and assessed tactically is at odds with the likely outcome when viewed and assessed more strategically and politically. This dilemma can be a challenge, especially in situations with increasing degrees of uncertainty, ambiguity and social complexity, where individual commanders are being faced with internally conflicting objectives.

Theory is developed to show that the geometrical forms of expected utilities, which arise from the assumption of commander rationality[49], are qualitatively stable in a wide range of scenarios. This expected utility theory opens out into further analysis linking to Catastrophe Theory as it relates to C2 regulatory frameworks for devolving command decision freedoms for choice. The paper demonstrates how an appreciation of this form of geometry can aid understanding of the relationship between socially complex operational environments and the prevailing choices open to commanders. The theory presented, therefore, suggests initial ways to explore and gain insight into different approaches to regulation of C2 decision-making aimed ultimately at achieving C2 agility, or at least at achieving a conceptual language to allow its formal representation. C2 regulatory agents are discussed in terms of detailed functions for moderating command decision-making, as appropriate for the degrees of uncertainty and goal contention being faced. The work also begins to address implications of any lack of experience and any differences in personality-type of the individual commanders with respect to risk-taking, open-mindedness and creativity. It is noted in the paper that the use of the Catastrophe Theory geometry, therefore, could also inform selection and training of personnel. The points made about C2 regulatory agents and moderating decision-making are taken further in Dodd (2010) and is elaborated on in Dodd (2018b) in terms of choice-making. The points made about C2 agility are discussed further in Dodd and Markham (2013) and, in particular the four orders of C2 agility, which are then taken further in Dodd (2018a) in terms of Staged Appreciation, as a way of opening out into the higher orders of agility.

This thesis proposes that command and leadership decisions are increasingly being made under such conditions of internal contention. A key point of reference, at this early stage, is the inter-relationship between a subject's preferred course of action and their focus of attention in situation awareness; in particular, if there was doubt or uncertainty in situational information then it could easily be ignored, especially if it added to (or further confused) the degree of internal contention being felt.

The contribution of Publication 2 is the development of a cusp catastrophe model to capture the choice-making effects of ambiguity and confusion, when values and objectives, encoded in terms of a regulatory framework, are seen by a subject to be in internal contention.

Publication 3: A Theory of Choice

Dodd L (2011) A Theory of Choices: melding black swans, butterflies and swallowtails, *Proceedings of 8th International Conference on Complexity Science*, June, Boston, USA.

Publication 3 grew from a previous paper (Dodd, Stamp and Prins, 2008) presented at the International Conference on Complexity Science, which discusses the impact of going from closed eyes and mind to open eyes and mind; in particular, examining how thinking more openly about complexity (i.e. holding wide, yet focused attention (Milner, 1986)) through open, reflective thinking and creative thinking, may help to provide support for choice-making. Publication 3 moves towards a formal

[49] The use of the concept of rationality here does not presume any objective notion of 'being rational'. Rationality here means that each commander holds to their rationale, which is based on their view of the situation and their measures for assessing likely outcomes.

mathematical foundation for developing new ways of seeing choices (i.e. options relating to focus of attention, interpretations of a situation, and courses of action, adaptation and/or transformation), when there is both a complex social mix[50] and a challenging degree of open-endedness, uncertainty, ambiguity, confusion, volatility, contention and unknowns in the situations being faced.

The theory provides insight and supports reasoning about the challenges brought about by differences in ways of sensing, observing, noticing, interpreting, modelling, assessing, adapting and acting in an increasingly open and complex world. As such, it addresses questions that have formed the basis for this study, namely:

- Where do a subject's choices and the associated limits on choices emerge from and how do the limits on choice reflect on states of sense-making and focus of attention?

- Why and how do the nature and scope of choices tend, often dramatically, to shape the emergent behaviours within and between complex adaptive systems?

This paper is the first introduction to the *four* Catastrophe Theory models: the fold, cusp, swallowtail and butterfly, as described by four parameters, which represent certain elements of choice:

Parameter *a*: Referred to as a normal factor, which can represent whatever a subject chooses to monitor for maintaining and normalising behaviours, outcomes, measures, indicators, etc. These can then focus choose-ables down to those that are seen to be steady[51] and that help to normalise.

Parameter *b*: Referred to as the splitting factor which represents the subject's degree of confusion or discomfort felt due to a situation being uncertain, volatile, ambiguous, ambivalent and/or pertaining to two or more conflicting preference functions. It is called the splitting factor because when the need to act to maintain normality (as according to increases in parameter *a*) increases at the same time as a subject's confusion is increasing then their choose-ables tend to split into just two alternatives. This is often manifested biologically as bi-polar conditions and also as behaviours (e.g. fight-flight).

Parameters *c*: (describing the swallowtail and butterfly catastrophe[52] surfaces respectively) Represents two broad areas of a subject's internal contention based on attitudes to anticipation and assessment:

> *c1*: differences in a subject's need for projecting futures (e.g. need to predict precisely or being open to possibilities) and beliefs in possible/likely/probable futures;
>
> *c2*: differences in perspectives and measures of motivation (or loss/gain).

The theory makes the assumption that choices are made, thence decisions taken, according to a principle of viability or sustainability such that any chooser or decider (or deciding agent) is striving, where deemed possible, to preserve such a principle, according to whatever is the subject's scope of

[50] Note that the complex mix can extend to objects and agents that form part of the social mix but are not necessarily all human (e.g. a mix of people and AI agents).
[51] Vickers (1972) captures the essence of the difficulty here in trying to open-up the range of choose-ables, when the subject's focus is on stabilising and normalising.
[52] Note that in Chapter 2, Section 2.6, Table 2-4 the parameter *c2* is represented as 'd' to be consistent with Zeeman (1976).

interest and concern. For instance, in a particular setting, such a principle could be imagined to be preserving what might maintain the likelihood of loss (e.g. of life, money, power, stability, reputation, etc) at as low a level as possible, given the subject's view and understanding of their own circumstances.

The fold catastrophe is described as being normalising or stabilising according to a singular factor (represented by Parameter *a*) that combines the foci of interest into one considered 'state of being'. If there is no room for concern for anything other than a need for normalising or stabilising of a situation, even to the exclusion of explicit consideration of a subject's values and identity, then the relevant catastrophe surface is the fold catastrophe. This is dependent only on the first parameter (*a*: the normal factor). Any subject acting as a machine[53] would be described in terms of their choose-ables using this 'threshold' parameter and the choose-ables generally are either to make a change in current active state or to carry on.

If, in addition to concern for sensing and normalising, there is also included into parameter *a,* concern for situational understanding, then the relevant catastrophe surface is the cusp catastrophe. This is dependent on the first two parameters (*a*: the normal factor and *b*: the splitting factor). In the cusp catastrophe model, the splitting factor describes the way in which the set of choose-ables goes from a smooth and relatively open set, through a singularity to a bifurcated set of two choose-ables. These choose-ables become increasingly extreme as the splitting factor and the normalising factor increase together. There are many examples of such resultant behaviours in nature, such as the so-called 'fight-flight' and 'hypo-hyper' syndromes (e.g. hypo-thyroidism and hyper thyroidism). Both of the extreme choose-ables offer stable local minima in terms of the subject's sense of likelihood of loss. Here the subject is left with whatever alternative the prevailing conditions have led up to, until a tipping point is reached, when a tiny change in the subject's sensed state results in a jump from the one extreme to the other (e.g. rapid jump from flight to fight).

If, in addition to these two concerns, there is further concern for managing differences in beliefs regarding projected future outcomes, then the subject is opening their senses to other views and also opening their understanding and beliefs about the future to other forms of interpretation and projection. Here, the swallowtail catastrophe (Parameters *a, b, c1*) is appropriate, where the 'black swan' phenomenon (Taleb, 2008) occurs as senses are challenged by these 'out of model' events; but, unless interpretive 'models' can be opened and broadened, the subject will return to the original comfort of closed senses and closed choices[54].

Further, in addition to the previous three concerns, if there is concern for others' differences in preference, perspective and measures of success or failure, and the subject is trying to find social balance and consensus then the relevant catastrophe surface is the butterfly (parameters *a, b, c1* and *c2*). The key to staying comfortably open is to throw light onto the choose-ables. This allows a subject

[53] Here the subject could actually be a machine or a simple purposive switch. In this instance, a useful descriptive representation of the nature of choice, and the set of choose-ables, necessarily precludes any capacity or freedom to change the set of choose-ables.

[54] The strangeness of the black swan can then comfortably be seen and interpreted as a white swan that has been covered in dirty oil, because the subject knows how to deal with white swans so no change is needed and business as usual can resume.

to be openly prepared for and, therefore, to sense the existence of a third surface, which is the key to ongoing adaptation and mutually beneficial transformation or agility.

A combination of the concepts underlying the four parameters of Catastrophe Theory provides the foundation for a theory of choices. For example, as a subject's awareness narrows and acknowledgement of a broader set of preferences and beliefs wanes (or indeed may never have been there at all), there is a diminishing need for that subject to have any freedom to make changes to their set of choose-ables. Indeed, there are often instances of institutional 'choice-blockers' in terms of imposed ways of working and ways of thinking and behaving. Different complex adaptive systems will tend to have different freedoms for choice; that is, organisations or people who select only from their fixed set of choose-ables; through to organisations or people who are continually open to moving between their various sets of choose-ables.

If it is possible to refer to the four catastrophe models to describe where any subject might tend to be, for instance, in system 'levels' terms, then that could help in understanding why different sets of choose-ables tend to exclude or include any considerations of the four parameters; a, b, c1 and c2. Having such a theory of choices, or at least a basis for a conceptual framework, may then help in understanding why certain complex adaptive systems (and in particular certain 'cultural' mixes of them) can tend to exhibit behavioural syndromes, such as many repeated instances of "black swan events" or, more biologically speaking, hyper/hypo or fight/flight responses.

Publication 3 also hints at why open senses and open 'minds' are needed in preparation for times when opportunities for change and transformation are ripe, in order to be ready with some support for choice-making based on the mathematics of swallowtails and butterflies. It works through Cultural Theory to draw out what might underlie the differences in different subjects' choice-making due to their self-to-world relationships. Cultural Theory (Thompson et al, 1990) as extended by Thompson (2008) and related to grid-group theory (Douglas, 2008) works to complement Catastrophe Theory when both are being brought together to explore choice-making. In Thompson (2008), four cultural attractor states are proposed to capture "where people are" (Staged Appreciation in Publication 6 (Dodd, 2018a)): Hierarchist, Individualist, Egalitarian and Fatalist. Each attractor state has a representative choice-making 'shape'. One assumption is that each cultural attractor state has a correspondingly different way of choosing due to the associated cultural nature of choose-ables. Then the representative choice landscape embodies the different natures of the belief and preference functions relating to the attractor states.

For example, agents falling more towards the Fatalist attractor will tend to have a more flattened preference function (in the extreme it might be a flat line if they really do not care about outcomes and leave all to fate). This flattening of the preference function then reduces the concern for predicting the future in material terms because "what happens happens". On the other hand, a Hierarchist will tend to have strong concern for outcomes, not only according to their own preference function but also according to at least one other preference function (often one level up or down, as is the case in Publication 1, which deals with a Command hierarchy (Dodd et al, 2004)). So, the Hierarchist is seen to be considering their options according to at least two different perspectives that are being held at

the different levels in the hierarchy. For instance, what might be locally deemed a good[55] choice may not be as 'good' when viewed more globally. The Individualist tends to hold a singular view of what constitutes the 'best' choice; hence there is a single minimum or maximum. The Hierarchist and the Individualist can be seen to be two extremes of a continuum that has resonance with Jacobs' (1992) Guardianship and Commercialism syndromes respectively.

The Egalitarian strives to maintain an implicit, presumed sense of what is "good for one and all" and holds tightly to a need for maintaining that shared normality and stability within the status quo; hence, the choice landscape can be represented metaphorically as a ball precariously balanced on a constructed hill and choices revolve around actions and behaviours that maintain and uphold normalised stability. The Fatalist has no care about what or how to choose personally, hence, the choice landscape can be represented metaphorically by a flat line along which the subject might be moved but with focus also on a workable degree of linear stability and regulated normality. The Egalitarian and the Fatalist can be seen to be two extremes of a continuum, along which the need for concern about controlling and normalising future material events and outcomes diminishes in importance going from Egalitarian towards Fatalist; or alternatively increases in going from Fatalist to Egalitarian[56].

Publication 3 does not clarify what defines the nature of the choice landscape upon which the attractor states might be imagined to 'sit'. This is addressed in Publications 5 and 6. However, Publication 3 does seek to reason about the ways in which the attractor states could be seen to be emergent properties of a diverse cultural mix, given the implicit boundaries and limits on ways in which varieties of choosers are able to relate to their surroundings and the nature of their choose-ables[57]. Catastrophe Theory, however, offers a way to describe how movement between the attractors may be being governed or understood. Therefore, by means of the extended cusp catastrophe model through a swallowtail model into a butterfly model, Publication 3 formalises the link between Cultural Theory and Catastrophe Theory. It also introduces the subjective concept of choose-ables. This publication stands as a key contribution to knowledge and also to the PhD study and this thesis, which then extends its four catastrophe models into a seven-fold order of choice framework, and so more space has been given to its description.

Publication 4: Orders of Agility

Dodd L and Markham G (2013) Orders of C2 agility and implications for information and decision-making, *International Command and Control Research Technology Symposium*, Institute of Defense Analysis, Virginia. CCRP Publications. https://apps.dtic.mil/dtic/tr/fulltext/u2/a587016.pdf

[55] Jackendoff (2006) presented eight aspects of 'good-ness' which are useful when considering different viewpoints and preference functions corresponding to the different attractor states.

[56] It is along the line from Fatalist to Egalitarian that Douglas' (2008) Grid-Group work points to explanations for 'lone-wolf' movement towards a worthy cause, where this movement could be called 'Radicalisation'.

[57] The chooser's freedom and capacity to be able to change their set of choose-ables is a key question here and leads into the basis for the differentiation and integration when discussing the catastrophe surfaces.

Dodd and Markham (2013) define four orders of agility and examine concepts of value in decision-making, leading to an ordered model of nested decision-making and decision-taking. A model of four orders of agility provides a unifying scheme for diverse interpretations of decision-making, which gives greater confidence that different conceptions of value and assessment measures can be organised systematically. This nested representation of orders of agility becomes a useful source of rigour.

Agility is a theme which arises in relation to a range of complex endeavours; in particular, C2 decision-making agility as an essential capability attribute for operating effectively in the context of future operations, which can be characterised by two forms of complexity:

- Situational complexity, reflected in situations with:
  - no obvious precedents;
  - uncertain outcomes;
  - shifting objectives;
  - issues with measuring progress.
- Organisational complexity, when people are working at different levels and with different degrees of:
  - co-operation and forms of coupling with partners;
  - unanticipated alliances;
  - interactions between multiple Instruments of Power.

Organisational complexity (i.e. social complexity relating to what lies between people, teams and organisations) is taken further in Publications 5 and 6. In essence, the first form of complexity is where the first four catastrophe models are most appropriate (as discussed in Publication 3) and the second form of complexity is where the three higher-orders of the catastrophe models tend to be more relevant.

Dodd and Markham (2012) focused on the different forms of time, as exhibited in, or as relevant to, the exercise of agility. The purpose of Publication 4 is to extend this earlier work to make more explicit the impact of the two different forms of time on decision-making. The nature of the decision-making can consider potential changes of any kind: this includes choose-ables that cover courses of action, ways of organising, and means of maintaining communication and collaboration. The paper discusses decision-making, and in particular the creation, tasking, configuration, execution and reporting of decision systems; for example, a planning team, tasked to develop a CoA, can be viewed as a decision system. These are organisational constructs that reflect on the dimensions of organisational behaviour (process, structure, participation, knowledge, etc.). The aim is to use the principles of orders of agility to understand the construction of the 'decision space' within which decision systems are operating.

As a subject's choose-ables move through threshold-variative-prospective orders of choice they are following the centre-to-outwards trajectories shown in Figure 4-1, with observation moving to anticipation through to eventual creative sense-making and more imaginative choice-making. This is correlated with moving from Chronos-time to Kairos-time (Jaques, 1982), where sensing and knowing depends on different forms of knowledge (into broadening appreciations of value leading to the next order). Publication 4 draws lessons from Publication 1 about agile C2; also from the nature of the C2 regulatory frameworks in Publication 2. It also draws on the theoretical basis developed in Publication 3. The contribution of Publication 4 is its setting-out of the four orders of agility in a nested form,

which is related to the conceptual framework based on types of decision roles and knowledge outlined by Dodd (2008). In this way Publication 4 makes a contribution to the understanding of the ordering of forms of time, knowledge and ways of sensing and sense-making as related to a subject's capability to imagine choices and their capacity to deem them possible. Most importantly, in terms of the development in this thesis of the outer three orders of choice, Publication 4 introduces the aspects of organisational complexity that are in the shaping layers within which the situational complexity resides. The issues around (see above) 'forms of coupling with partners' and 'alliances' starts to open-up questions about self-context and self-other boundaries, and ways of dividing or uniting the wider world. At this stage of the study though, the higher catastrophe models had not been addressed, as Publication 3 only considered the four parameters up to and including the Butterfly Catastrophe model.

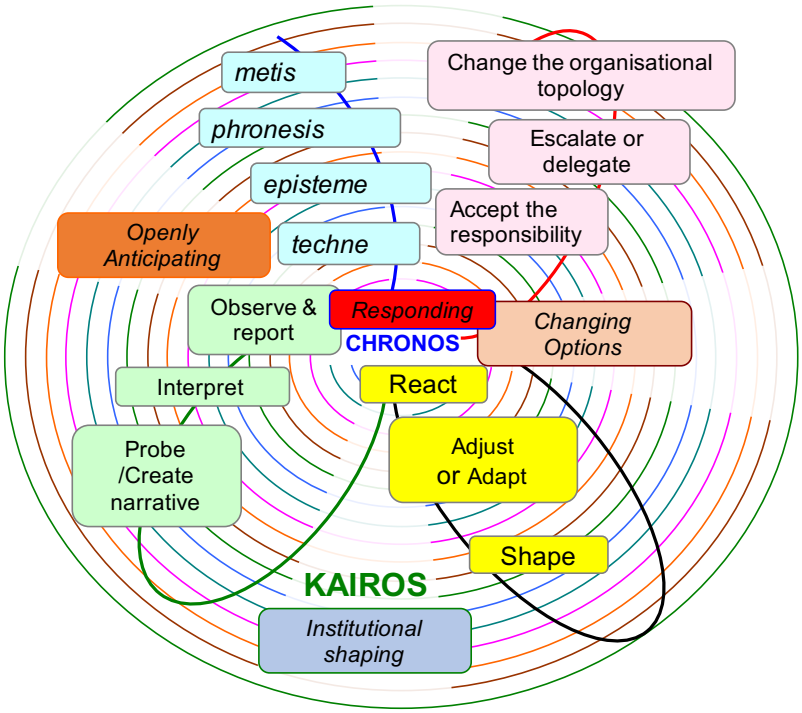

Figure 4-1: Orders with respect to forms of time, knowledge, and ways of sensing and sense-making (Dodd and Markham, 2012).

Publication 4 summarises that agility can be exercised, at the four different orders (i.e. pertaining to the first four orders of choice), through *activities.* These activities encompass:

- *instruction* – tasking, allocation, communication of constraint, restraint, preference or value;
- *application* - exercise of an instruction, constraint, restraint, preference or value;
- *violation* - of an application;
- *reporting* - of a successful application, or of a violation;
- *requesting* - of a suspension or modification;

- *suspension* - taking a local decision to rescind or not to apply an instruction;
- *creation* – of a new tasking, allocation or constraint;
- *modification* - effecting a change in an extant item which may then form the basis for an instruction.

Figure 4-2 shows the activities in relation to two adjacent orders, at each of which decisions are being taken and the results communicated to the other order. Again, the figure can be applied recursively to span the orders zero-to-three. The instructions being passed from the higher to the lower order may constitute either enablers or inhibitors of agility. In other words, the higher orders of agility may be pointing to constraints, restraints, preferences and values which, if not addressed, are the key inhibitors of agility at lower levels[58]. Change can be blocked, as well as enabled, by the higher-order activities. Figure 4-2 portrays a message-passing system, however, the two blocks in the figure (labelled 'Order n' and 'Order n+1') are a*bstract* or *virtual* 'nodes': they *may* be distinct in physical and/or structural terms, but they could equally well be referring to sets of activities taking place within the mind of a single individual.

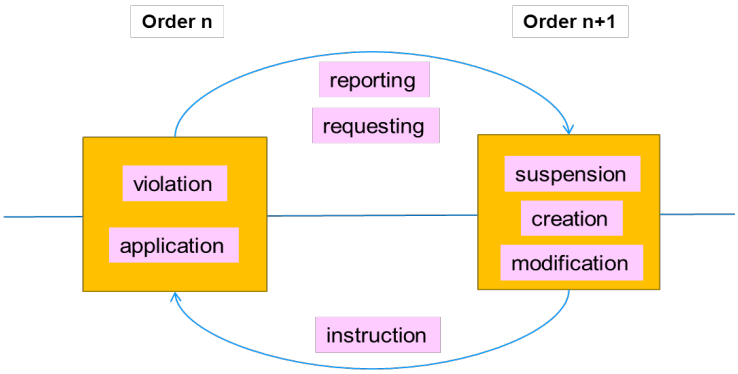

Figure 4-2: Activities shown on a simple recursive two-order model (Dodd and Markham, 2013).

Publication 4 provides the basis for extending the orders of choice out into the three outer layers and for use of the three higher-order catastrophe models. The concept of instruction is most important as it holds the in-structional link from the contextual order n+1 into order n. The other two linking activities, re-porting and re-questing, represent the ways in which the order n looks out into the contextual order n+1. The activities within the orders are those that check against sense of discomfort (i.e. application and violation) and those that are responsible for adaptation (i.e. suspension, creation and modification).

[58] Such changes can be capable of trumping the presence of other enablers and valencies (for example, the intellectual capacity of the commander to exercise 'first-order' creativity in coming up with novel courses of action).

Publication 5: Multi-perspective approach for complex, adaptive and inquiring systems

Dodd L and Alston A J (2009) Complex Adaptive and 'Inquiring' Systems Theory for Contemporary Military Operations: A Multi-perspective Approach, *The Cornwallis Group XIV: Analysis of Societal Conflict and Counter-insurgency*, Vienna. http://www.ismor.com/cornwallis/workshop_2009.shtml

Publication 5 takes up the theme of Publications 1 and 2, moving away from traditional C2 research (i.e Publication 1 focused on direct support to decision-making) towards working through different perspectives (introduced in Publication 2) more formally and analytically. This could be seen as a straightforward step that is broadening the viewpoints of decision-makers; however, it is an acknowledgement that context and conditions are made up of other subjects (i.e. other cells, people, groups, organisations, etc), all of which have their own (usually different and maybe conflicting or contentious) perspectives on a situation. This multi-perspective nature of context presents a major challenge to existing decision theory and methods, which assume operating environments that are presented as 'situations' to be recognised. The challenge therefore is how to approach these more subjective contexts. This challenge is taken up by Publication 6, which suggests referring to a guiding framework where the subject of interest is a person, a group or an organisation or institution.

The research question that Publication 5 seeks to address is: if a subject is having to contend with increasing degrees of open-endedness (particularly in terms of the extent of anticipated consequences of actions due to unpredictability and social diversity), is it enough to extend and adapt existing methods? Publication 6 then goes further than asking just about methods of analysis, and asks how analysts might need to change their ways of thinking and working.

Bertalanffy (1969) identifies two 'classical science' approaches. The first is the tendency to reduce a problem into its constituent parts, which assumes that couplings between the parts are simplistic (e.g. as mechanical levers). The second condition is that the behaviour of the parts is linear, which allows the elements of the problem to be treated statistically. Bertalanffy (1969) then goes on to reason that traditional ways of thinking tend to fail where there are large numbers of nodes and interactions, and when the couplings between the nodes and interactions increase in intricacy. This highlights that there is a sizeable white space in Figure 4-3 that is not covered by classical science. This 'white space' is the area of interest for this thesis; in particular, addressing the coping strategies that subjects adopt in order to remain comfortable while having to engage with, and be within, the white space. Essentially, this thesis is addressing both axes[59]: the vertical axis is what represents the increasing challenge of projection into the future (i.e. the situational complexity); and, the horizontal axis is what represents the increasingly intricate nature of inter-relationships (i.e. the organisational and social complexity). The coping strategies that come into play when a subject is faced with both forms of complexity then become a discussion based around a subject's choose-ables, and their ways of sensing and sense-making.

[59] Note that the orthogonality of the axes in Figure 4-3 is there for diagrammatic convenience and so it is not assumed that these two forms of complexity are in any way independent; indeed, it is the inter-relationship between the two that the nesting of the orders of choice addresses.

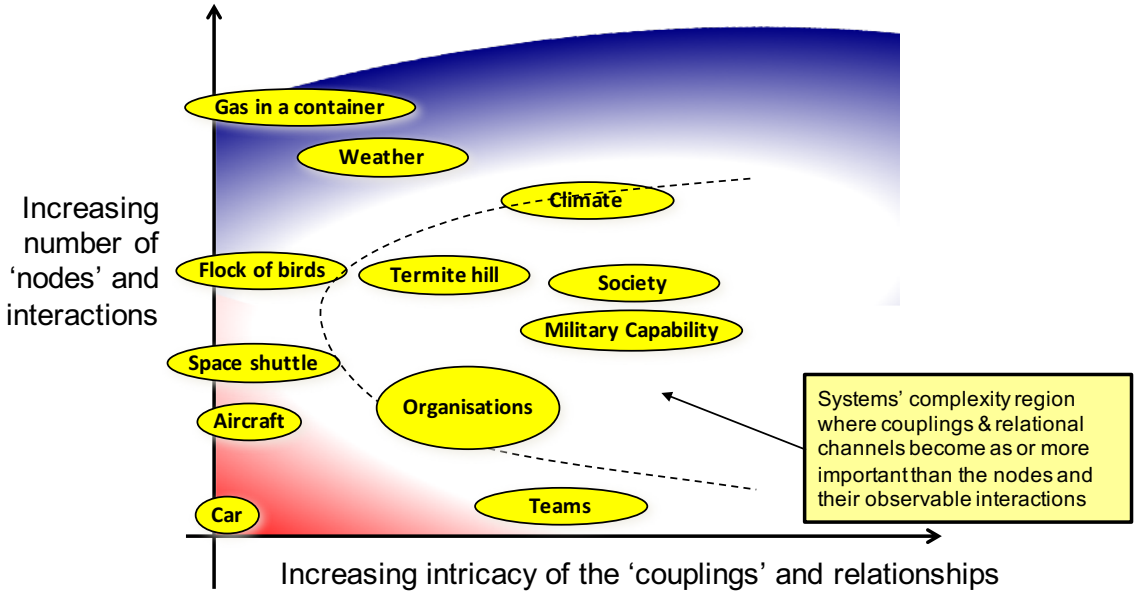

Figure 4-3: Complexity space schematic with illustrative examples of systems (Alston and Dodd, 2009)

The challenge of subjects, with their different perspectives on their situation, demands a return to holistic, inquiring systems thinking (Churchman, 1971). Traditional decision-theory approaches that optimise "expected pay-off" functions need to move towards subjective, multi-perspective representations, whilst moving from preparing for the probable to being able to engage with the possible; such as proposed by Shackle (1976).

A conceptual framework is presented from which analytical frameworks can be drawn such that the methods used for problem analysis have sufficient degrees of freedom and requisite variety to match the characteristics of the challenges posed by contemporary operations. A case study based on Counter-Improvised Explosive Devices (CIED) in Afghanistan is used to illustrate the conceptual and analytical frameworks.

Publication 5 draws lessons about subjectivity from Publications 2 and 3 to address the scope of choose-ables across a range of perspectives whose subjects may be intricately coupled. Publication 5 contributes an analytical framework and a choose-able 'landscape' for resolving choice-making across a range of different perspectives (i.e. differences in terms of what matters to different subjects and how that shapes their viewpoints). This multi-perspective approach then becomes a focus for the Staged Appreciation being proposed in Publication 6.

Publication 6: Staged Appreciation for Socially Complex Situations

Dodd L (2018a) Techne and techniques for engaging in a socially complex world, *Journal of the Operational Research Society*, 70:9, DOI: 10.1080/01605682.2018.1501461

Publication 6 addresses the challenges faced by analysts in moving beyond traditional forms of analysis and modelling towards more relational forms. This challenge puts more emphasis on reflective practice, people and relationships. Therefore, a Staged Appreciation is proposed as an overall guiding framework. This paper then presents a small selection of illustrative techniques for engaging with social complexity. Guided by Staged Appreciation, these techniques add an insightful new dimension to knowledge sharing for understanding, and for reflecting upon the intricacies involved in socially complex situations.

There are analytical advantages to standing apart from a complex situation; however, this remote standpoint tends to ignore the involvement of the analyst's perspective in sensing and understanding the social complexity of the situation. Their beliefs and values could be as impactful, and as important for holding up for reflection, as the perspectives they are standing back to analyse. So, Staged Appreciation complements the analytical standpoint by asking them to take a more reflective view of their own working relationships, becoming more *a part of* the socially complex problem as well as standing *apart from* it. Staged Appreciation offers a reflective framework for working with Systems Thinking techniques and together they complement traditional practice. Publication 6 aims to support analysts when adopting a more reflective and relational view of a complex problematic situation in order to see it 'as a whole'. The paper draws lessons from holism, reflective practice and subjective analysis.

If analysts are to address socially complex problems then the paper proposes that there may be a need for some complementary techniques that will help to:

- Look at people as people and not as "things" (e.g. as nodes in a network, or as human resources);
- Be subjective as well as objective; for example, imagining situations from a subject's perspective as well as from an analytical perspective;
- Broaden focus so that compromise resolutions might be found that go beyond the usual objective indicators and measures that lead only to a single-point optimal solution;
- See the problem from different perspectives (e.g. so what seems to be "the best" from one perspective can be resolved for situations with multiple stakeholders);
- Highlight the interactions between things and events; and, more importantly, the intricacy of inter-relationships between people (i.e. couplings, social bonds);
- See the problematic situation, reflectively, as a whole.

Today's problematic situations are becoming more complex (Bar Yam, 2005). According to the complexity scientists, increasing complexity tends to be attributed to an unbounded number of elements and interactions and an increasing rate of events[60]. Previous papers on so-called 'wicked problems' (Roberts, 2000) and previous studies (Dodd and Alston, 2009) have suggested that complexity has another important dimension, which relates to the increasing intricacy of couplings and inter-relationships (Flood and Carson, 1993). It is the nature of this inherent inter-relational intricacy that forms the context for this paper.

[60] In Publication 5 this is represented by the vertical axis in Figure 4-3.

When problems are looked at objectively, they tend to be viewed in terms of the quantitative dimension of complexity (i.e. vertical dimension in Figure 4-3). The inherent social and personal complexity of human systems (Vickers, 1983) (i.e. horizontal dimension in Figure 4-3) is not being addressed or, if it is being considered, the relationships tend to be treated as 'levers' (e.g. cause-effect levers). So, the first question that this paper poses is: 'What is available to help analysts appreciate more fully the intricate, personal and relational nature of the complexity in the situation as a whole?'

For this purpose, Staged Appreciation is proposed as a form of 'techne', which captures the essence of what it is to master a skill, and as such could be used as a guiding check-list as analysts work with people through complex problems. This check-list approach is in the spirit of Dr Atul Gawande (2014) who proposed such an approach in his 2014 Reith Lectures, in order to aid with the "messy intersection of science and human fallibility".

Staged Appreciation (Dodd, Alston and Stamp, 2010) follows six inter-related stages:

Where people are: this acknowledges that 'where *people* are' is the most important consideration, and that this positioning of people has many aspects; so, it could be in socio-geographical or socio-demographic terms, and socio-cultural/political terms and it could be in terms of their capacity for sensing the extent of the situation and for making sense of the unbounded complexity of the situation.

Open-eyes/open-mind: explicitly addresses how people might be approaching their sensing and sense-making; so, for example, if people are only looking at the pre-defined indicators or parameters and using extrapolation of past indicator-based trends, then this closed-eyes/closed-mind approach, in itself, forms a large part of the broader problematic situation.

Belief and surprise: elicits what people believe through asking what might surprise them, as shown at Figure 4-4; so, for example, if people have been greatly surprised by the consequences of a considered decision, (e.g. they believe that use of Method A will help to solve Problem X) then they are more likely to openly appreciate and reflect on their previously held belief about what could happen and adapt accordingly.

Choice-making and choose-ables: suggests that people's choose-ables tend to limit and colour their views on a situation; so, for example, if people can only consider or countenance two ways forward, then the situation will be viewed in black and white or 'us-them' terms. If people can be helped to see beyond their current or comfortable ways forward and to relate to others' choose-ables, then this proffers more open understanding of the potential benefits of novel options for resolution.

Focus and preference: intricately related to belief and choose-ables; so, if all of these can be openly appreciated then 'where people are' (especially in terms of open-eyes and open-mind) can be addressed as being part of the problematic situation. This applies directly to the analyst or the problem structurer or facilitator.

Multi-perspectives: can now be appreciated with a richer understanding of the diverse range of people's views, and of people's deeply held lines of perspective, that can be hidden deep within a problematic situation, when ways of being and doing are dear to people's hearts, minds, behaviours and lives.

This final stage draws on the multi-perspective approach introduced in Publication 5, which offers a technique that makes explicit the analyst's system of interest or focus (e.g. the key issue in a policy statement), draws out the key stakeholders' perspectives on that focus of interest and, importantly, also considers the inter-relationships between the stakeholders.

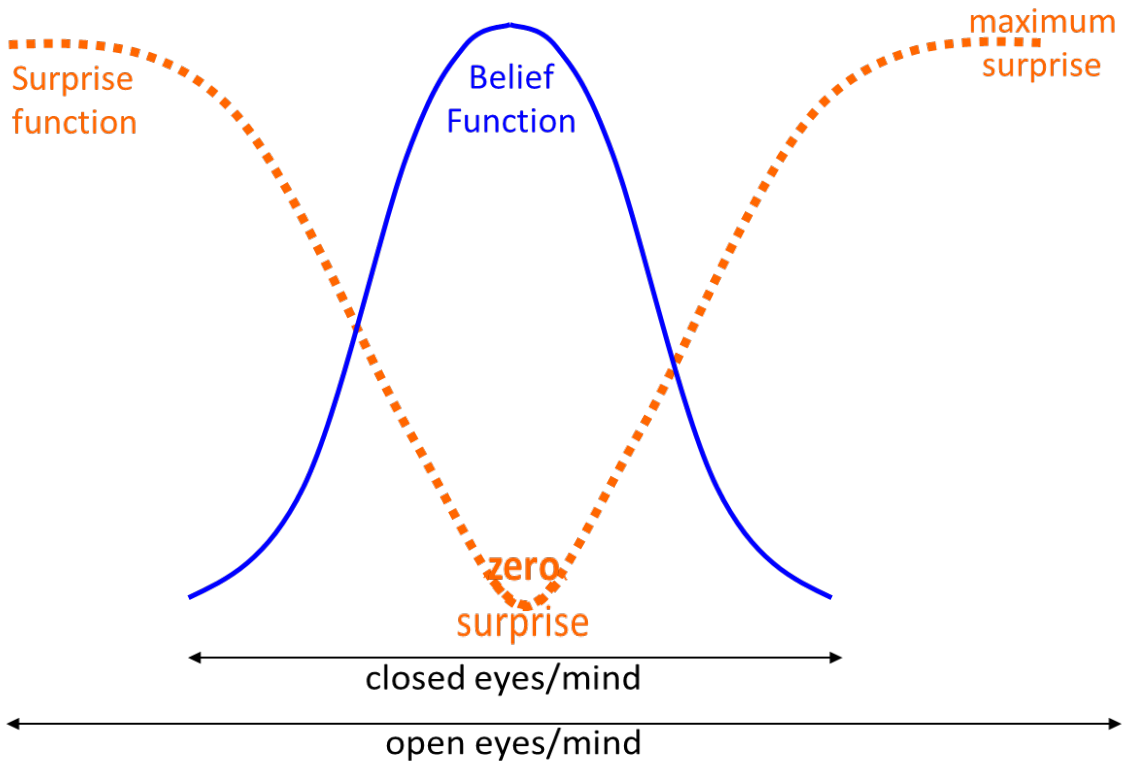

Figure 4-4: Surprise as the inverse of belief relating to open-eyes/open-mind (Source: Author).

There are other useful frameworks such as Critical Systems Heuristics (CSH) (Ulrich, 2003) to show how holding to a single analytical measure of success can dominate analysis, such that it determines problem-solutions and limits perspectives. CSH can help analysts (and also those involved in coming together to set policies) to mitigate against particular Measures of Success (MoS) dominating analyses. CHS makes the MoS explicit and links the MoS directly to those involved, who may be working through power dynamics to serve their own interests rather than seeking shared interests. CSH is discussed further in relation to Staged Appreciation, Problem Structuring Methods (PSM) and System of Systems Methodology (SOSM) to show a nested set of approaches to problem solving, problem formulation, problem understanding, and finally problematic situation appreciation. This nested set of approaches forms a landscape that represents the increasing relational intricacy being addressed as the analyst moves from the centre outwards through the layers. It is not that the situation will always demand the approach that sits in the most outward layer. The notion that can be used, as a guiding 'yardstick', is requisite variety (Ashby, 1958). The variety (i.e. in this case the relational intricacy) of the situation needs to be matched by the variety of the appreciative system that is trying to understand and potentially regulate or govern the situation (Conant and Ashby, 1970).

As an example, the academic and practice-based landscape of the development of OR and Management Science (OR/MS) is comprehensively reviewed in Jackson, (2006), in this instance the framework for positioning PSM is defined using categories of problem: simple or complex; set against natures of participation: unitary, pluralist, coercive (adapted from (Flood and Jackson, 1991). This is a useful framework, but it relies on the analyst's capability to appreciate the situation as a whole and being able to then categorise the situation as simple or complex and according to whether it has unitary, pluralist or coercive natures of participation. So, rather than arrange methods and approaches as a segmented framework (Jackson, 2006), Figure 4-5 shows a nested view of that problematic situation landscape. Following from Ulrich (2017), the kinds of questions typically posed in each layer are presented to show how Staged Appreciation relates to CSH, PSM and OR/MS respectively.

Jackson (2006) also discusses Morgan's (1997) metaphors, listing them in terms of seeing "organisations as". Alternatively, and more relationally-speaking, this nested view distinguishes relational boundaries (as drawn by the ellipses in Figure 4-5) according to how the nature of organisation (i.e. the degree of intricacy of what lies between) is being viewed or imagined when working in each of the layers. The inner layer is where OR/MS sees organisation as purposive couplings between elements or events (e.g. cause-effect). The next layer is where PSM sees organisation as structural couplings, and the next layer is where CSH sees organisation as cultural and political relationships. The next layer is where Staged Appreciation sees organisation as inter-personal. Staged Appreciation subsumes, and so works around and within, the other layers. Jackson (2006) suggests an additional "carnival" metaphor. Staged Appreciation suggests 'organisation as dance', where each person is an individual, each appreciating the dynamic relationship with opportunity for creativity and innovation.

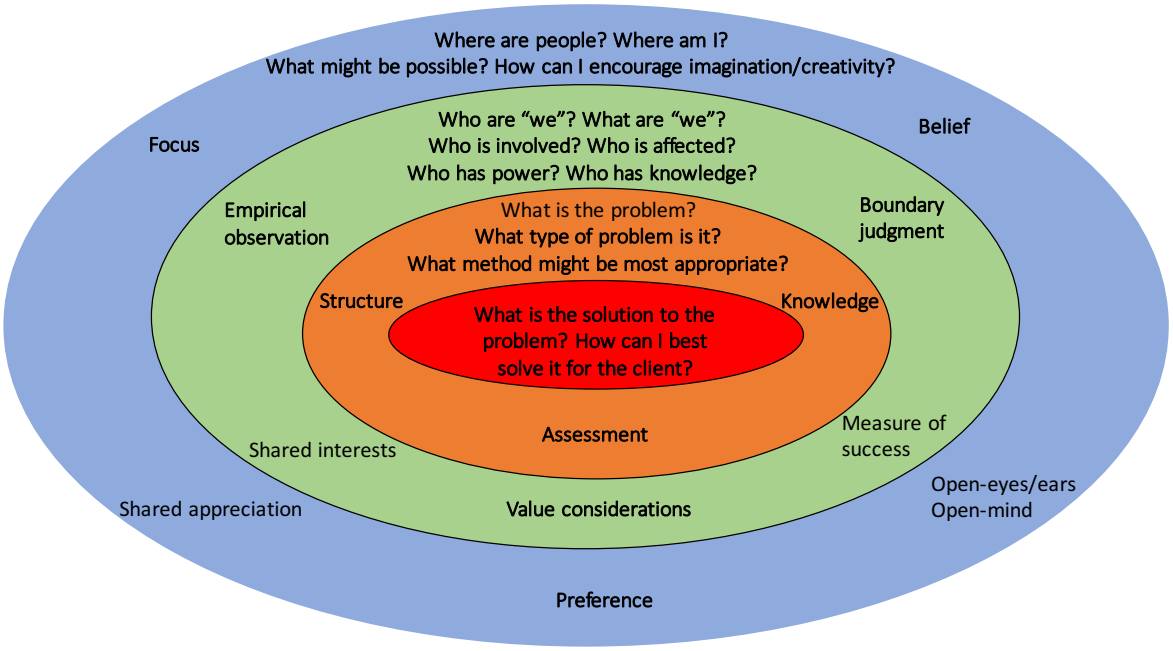

Figure 4-5: Staged Appreciation working through and within CSH (Source: Author).

The contribution made by Publication 6 is a formalised Staged Appreciation approach to subjective, reflective analysis to ensure that reflective analysis works through the fundamentals of the different subjective viewpoints, in terms of their different foci of attention for sensing, different belief models for sense-making, and different preferences, all of which tend to lead towards different scopes of choose-ables and could also be ranged across different natures of choose-ables.

Publication 7: Choice-making and choose-ables

Dodd L (2018b) Choice-making and choose-ables: making decision agents more human and choosy. *Euro Journal on Decision Processes*, Volume 7, Issue 1–2, pp. 101–115
https://doi.org/10.1007/s40070-018-0092-5

Publication 7 returns to the concepts that might shape, extend, limit or re-focus a subject's set of choose-ables, that can then be thought of as that particular subject's *potential* in terms of their ways forward and degrees of freedom. Because there is no unambiguous word that conveys the meaning of this higher-order concept of choice-making, the term 'choose-able' has been adopted from work by Shackle (1976) as reported by Ebeling (1983; p6):

> "*Your list of choosable things has to be constructed or composed by yourself before you can choose*".

The adoption of the term choose-able is to extend the usefulness of the concept for the purposes of relating it, more formally through a Catastrophe Theory construct, to subjective and contextual factors drawn from Cultural Theory; also, to relate a subject's open-ness or closed-ness of sensing and sense-making to that subject's nature and scope of choose-ables.

Publication 7 is written from the point of view of extending agents (e.g. Artificial Intelligence (AI) agents or algorithms in agent-based models) so that they might be able to consider their choices; rather than agents simply selecting from a set of pre-determined options. Therefore, Publication 7 uses the concept of a choose-able to distinguish it from the more usual agent decision-making concepts, usually referred to as 'option' or 'choice'. An agent's choose-ables are defined (as above) as the imagined deemed possible ways forward, that an agent has to construct, compose, countenance or create before they can choose. The central concept of a choose-able is a very powerful one, if only it can be surfaced and made explicit. It is often only possible to make inferences about the nature of choose-ables after observing the actions taken once a choice has been made and a decisive action has been taken.

The paper presents a funnelling construct to depict the ways in which an agent's imaginable options might be being discounted or disallowed due to regulation and feelings of discomfort or capability. The paper then develops the ideas introduced in Publication 3, as it draws together Catastrophe Theory and Cultural Theory to offer new ways of analysing the shaping effects of relational contexts on an agent's choose-ables. These then act as a medium through which agents are drawn to make choices and carry out observable actions. The strength of the combination of the theories lies in their

descriptive power of subjective, relational concepts that hitherto have tended to remain hidden and tacit. This paper, as a central study area for this thesis, is an exploration of why an agent's (or any subject's) circumstances and relational conditioning might shape or directly affect their choose-ables. The central question being addressed is:

What might be intrinsically or extrinsically affecting an agent's degree of decision freedom?

Publication 7 sets about understanding conditions for the shaping of choose-ables, from which decisive consequences may (or may not) then flow. It is trying to reflect a more subjective approach to thinking about how an agent's potential for choice might be scoped or broadened. The approach works through from contextual, subjective conditions to consequential potential, via a notional 'funnelling' that works to either limit or open-up an agent's choose-ables.

Choose-ables cover the possible ways forward that any agent:

- Can conceive of (or imagine);
- Would countenance as being one of their choose-ables (e.g. within their moral code[61]);
- Feel are open to them for choice (e.g. given their relational circumstances);
- Feel they are obliged to consider;
- Feel competent to consider; and/or
- Feel they are barred from considering (e.g. social taboos).

There are strong similarities with the concept of affordance (Bradshaw et al, 2004) in that choose-ables describe the subjective contextual nature of the opportunities for choice-making and the 'wiggle room' for consideration of potential ways forward. Affordances are properties of the context taken relative to any person or agent (Wells, 2002) and, as such, they do not explicitly define that agent's constraints or desires, being more about perception of environment inviting an active response. Affordances pertain to the context but are relative to and subject to what that context offers, opens-up or closes off, perceptually as well as operationally (Gibson 1979), for that decision agent in their current personal circumstances.

These studies of affordance do not explicitly include the agent's capabilities in terms of what might be predicted to be probable outcomes of decisions[62], both of which will further affect an agent's ultimate choice of option. An agent's appreciation of how difficult or impossible it is to predict future outcomes is related to their ability to look at context. That difficulty or impossibility to predict tends to increase with complexity and intricacy of context.

In essence, the paper proposes conceptual extensions into higher orders of decision agility (Dodd and Markham, 2013) and higher levels of adaptation (Grisogono, 2004) to reason about an agent's potential or degrees of freedom for choice. The proposed conceptual frameworks are underpinned by developmental theories drawn from the mathematics of discontinuity (Zeeman, 1977), subjective economics (Shackle, 1976) and from Cultural Theory studies (Thompson et al, 1990; Thompson, 2008; Douglas, 2008). The aim is to address how levels of adaptation might be extended within decision

[61] There are deeper philosophical foundations that need to be mentioned here (Arendt 1958).

[62] In terms of 'Ways, Means, Ends' the focus here is firmly on the scope and nature of the ways forward and is not directly concerned with the available means or the desired operational ends.

agent frameworks to capture how and why agents might limit or extend their choose-ables (as listed previously).

This paper provides a framework for reasoning why agents might be subjectively scoping their focused set of options and how the ever-changing context is working to shape their choose-ables. It offers a way to address (and maybe eventually to encode), as a whole, what might subjectively scope, shape, constrain, restrain, open-up, extend or enhance an agent's choose-ables. The nearest there is to a collective concept might be referred to as an agent's portfolio of choices that are deemed to be 'OK' by them and for them to choose from. The important point being that the nature of that deeming of 'OK-ness' is temporally subjective; that is, according to that agent (or agency) at that time and in terms of their particular circumstances and concept of time span.

The collective concept of a portfolio of choices can also relate to a person, group or an agency, as noted by Sylvan and Voss (1998; preface):

> "*Previous studies of foreign policy decision making have largely focused on the choice among specified options rather than the prior question of how the options were specified in the first place*."

The study of 'how the options were specified in the first place' requires a step back to explore what might be happening in an agent's relational, cultural, 'personal', organisational and temporal contexts. This further requires access to an agent's implicit, trust-based, rationale for what they might (or might not) be open to considering as one of their choose-ables, given their current circumstances and 'personal' experience to date. For example, a vegetarian 'agent' in their everyday circumstances would not countenance having 'eat meat' as one of their choose-ables; however, if their circumstance involved being in a position of extreme hunger and they were being kindly and generously offered meat stew, then they may extend the scope of their choose-ables temporarily to include 'eat meat'. The strength of their cultural relationships and personal positioning plays a large part too (Douglas, 2008). For example, if the agent is bound by a patriarchal grid structure or if they choose to conform to the values of a social group, then their degree of autonomy in choice-making will be appropriately and relatively shaped or biased.

Choose-ables are, therefore, subjective and personal and tend to be shaped, limited and/or opened-up according not only to an agent's context but also to the extent and nature of their awareness of that context. This contextual framing can also extend the concept of a choose-able to be not only about active ways forward (e.g. eating meat), but also ways of making sense of situations (e.g. interpreting a scene as A or B), of where to place their attention (e.g. focused or wide attention[63]), or what to believe, whose preferences to take account of, etc. This can be extended further to consider decision agents (e.g. agents representing managers) whose choose-ables might be organisational in nature (e.g. empowerment of others) or ways to shape relationships (e.g. building of governance relationships).

[63] "The second way of perceiving seemed to occur when the questioning purposes were held in leash. Then, since one wanted nothing, there was no need to select one item to look at rather than another, so it became possible to look at the whole at once" (Milner, 1986; p106)

The basis for Publication 4 (Dodd, 2011) is that choose-ables tend to frame the ways in which agents may be able to sense, feel, interpret, discern, assess, adapt and act in their world. In turn, all of these are shaped and conditioned by the nature and scope of the ways forward that appear to be open to them at the time of need for choice-making and decision-making. For example, if an agent has only one way forward then the situation may need to be seen and framed to fit that one way forward to provide the comfort of knowing and of having 'the solution' to the problem; as in: if I only have a hammer, then every situation for me becomes a nail to be struck.

As an instance of a collective agent being restrained by institutional and governmental laws and regulations, Western governments, bound by accountability and strict legal scrutiny, are often restricted to having only one choose-able, such as imposing sanctions. Their focus on sanctions then tends to limit the way in which they see and make sense of the situation. This naturally suggests that the influences flow both ways between the sensing or sense-making and the choose-ables that are seemingly open for choice; therefore, having a closed mind and firmly focused eyes tends to close-off options for choice; however, not being open to more options for choice tends towards finding comfort in one's closed mind and ears and focused eyes.

Publication 7 looks in detail at the natures and scopes of choose-ables in order that decision-agents might be extended and enhanced by addressing choice-making. The contribution made by Publication 7 is focused more on the subject's deeming possible of choices building on the concept of affordance and making this concept more subjective and related to a subject's motivations and drives with respect to their conformance to regulatory structures. Publication 7's contribution is subjective choice-making in terms of a subject's scope of choose-ables. This paves the way for this thesis to synthesise the contributions from all seven publications to provide a final contribution in the form of the orders of choice framework that addresses both the scope and the nature of choose-ables.

4.2. Theory development through the seven published works

The seven publications introduce the supporting theories and also describe the background experimental work that prompted the development of the framework for orders of choice. This exposition takes a broad look at the concepts underlying the two key theories: Catastrophe Theory and Cultural Theory. This philosophical view prompts further questions about the concept of invariance under conditions of adaptation and change. For instance, how can change or adaptation be discussed without a concept of time? Does time need to be taken to be linear or at least chronological? What is meant by non-linear change? This draws a dependence on the theories presented to address different forms of time, which is addressed in Publication 4 (Dodd and Markham, 2013) as well as exploring the topology of discontinuity, which is done in Publication 3 (Dodd, 2011) and then extended though the presentation of the seven catastrophe models. The theory for 'what might be shaping a subject's choices?' was introduced in Publication 3 (Dodd, 2011), which described the theory as providing insight and supporting reasoning, with which to open-up new questions. These questions still stand and can now be addressed more formally with reference to the orders of choice framework. The two questions in Publication 3 that directly address the overarching research question are:

- *Where do a subject's choose-ables and the associated limits on choices emerge from and how do the extents on choice reflect back on a subject's sense-making and their foci of attention?*

- *Why and how do the nature and scope of a subject's choose-ables tend, often discontinuously, to shape the emergent behaviours within and between a complex of subjects and contexts?"*

Regarding the emergence of a subject's choose-ables, the theory makes the assumption that choices are made according to a principle of maintaining minimum discomfort. This need to maintain low levels of discomfort at each of the seven nested orders in the framework is represented by the catastrophe models. As depicted in the sub-threshold sections of the iceberg in Chapter 1, Section 1.3, Figure 1-2, for any subject, the accessible natures and the scopes of the choose-ables depend on the ways in which the contextual orders build on each other, demonstrating how their sense of discomfort tends to shape their focus of attention and sense-making working up through their concepts of value. The sub-threshold layers of the iceberg, coupled with the systemic structural logic of the orders of choice, provide a formal language for deeper reasoning about a subject's ways of sense-making and their sensing of what, for them, lies above the threshold. So, subjective potential for sensing, sense-making and choosing can be formally related to the nested dynamics of the deeper, unseen regions of choice-making. The framework, therefore, provides understanding of the ways in which any emergent behaviours are being shaped, often through inter-layer discontinuities, as subjects sense, sense-make and choice-make within and between a whole complex of subjects and their contexts.

Figure 4-6 charts the journey through the publications. Publication 1 finds that subjective preferences tend to shape a subject's choices that in turn tend to impact on a subject's sensing, focus of attention and interest, and also their frames of reference for situational sense-making. This prompts, in Publication 2, a development of a cusp catastrophe model to capture the effects of ambiguity and confusion when values and objectives are seen by a subject to be in conflict. Publication 3 extends the cusp catastrophe model out to the swallowtail and butterfly models to look more at choice-making than decision-making to give a four-fold framework for choices, that also addresses scope of choose-ables through the introduction of Cultural Theory. Essentially, referring back to Chapter 2, Section 2.9, Figure 2-4, Publication 3, by means of the extended theory, formalises the link between Cultural Theory and Catastrophe Theory. It also introduces the subjective concept of choose-ables. Publication 4 is drawing lessons from Publication 1 about agile C2 and also the theoretical basis from Publications 2 and 3. In doing so it sets-out four orders of agility that are nested and related to the conceptual framework based on types of decision roles and knowledge outlined by Dodd (2008). Publication 5 draws from Publication 2 and 3 to address the scope of choose-ables providing an analytical framework and a choose-able 'landscape' for resolving different perspectives (i.e. differences in terms of what matters to different subjects and how that shapes their viewpoints). Publication 6 then formalises Staged Appreciation to ensure that reflective analysis works through the fundamentals of the different subjective viewpoints, in terms of their different foci of attention for sensing, different belief models for sense-making, and different preferences, all of which tended to lead towards different scopes of choose-ables, which could also be across different natures of choose-ables. Publication 7 looks in more detail, given specific natures of choice, at the scope of choose-ables in order that decision-agents might be extended and enhanced by addressing what shapes choice-making.

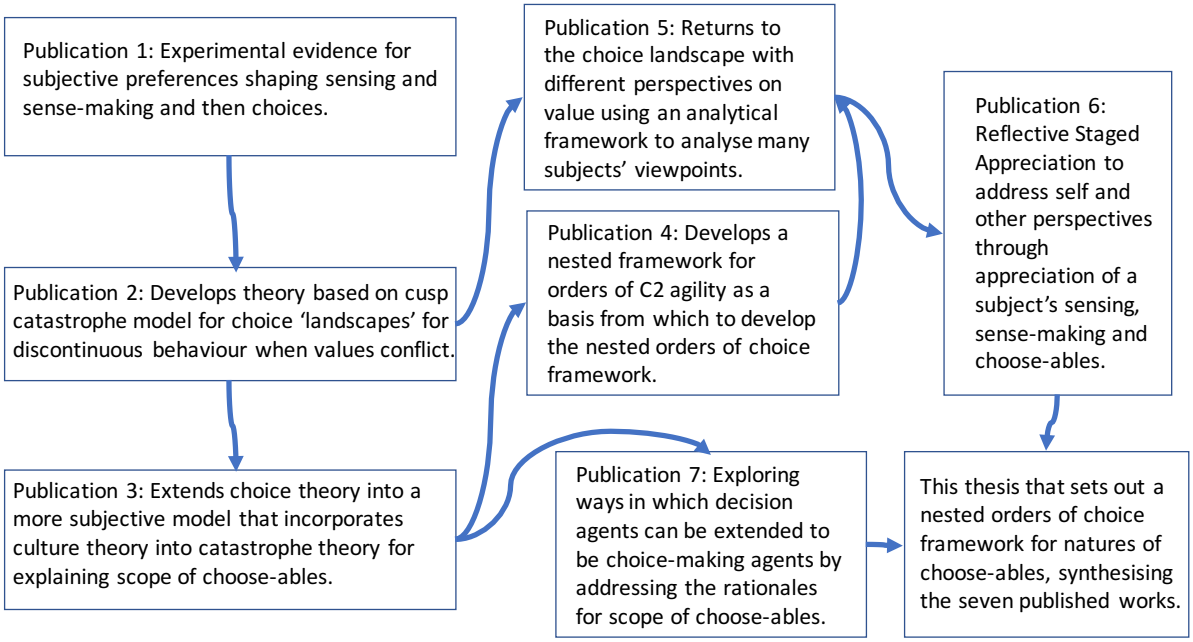

Figure 4-6: Charting the journey through the seven publications (Source: Author).

5. Summary discussion, challenges and future work

This chapter re-states the research gap and sets out why the orders of choice framework, resulting from the synthesis of the published works, addresses the four key aspects of this gap. It then returns to the overarching research question to show how the five earlier publications lead to that question, and then how the two later publications along with this thesis provide ways to form answers to that question. This chapter then makes recommendations for ways to use the orders of choice framework, highlighting some methodological challenges. Finally, it sets out avenues for future study.

5.1. Revisiting the research gap to demonstrate novelty

The literature in the field of decision-making and decision-taking addresses selection processes based on responsive options and as such does not extend broadly or formally into subjective choice-*making*. Because decision studies tend to be focused around responsive options, there is nothing of a formal, mathematical nature that proposes a theoretical framework for understanding other kinds of choices (e.g. based around choosing different self-context boundaries or self-other distinctions). So, there is no framework for positioning a subject's order of choice.

The research gap that this thesis is addressing emerges due to the lack of formal theoretical basis for study into how a subject's options for choice are settled upon by that subject. The main proposition is that, at any moment in time, a subject has subjective potential in the form of an associated range and scope of choose-ables, and that these can be ordered (or nested) according to the nature of the choices open to that subject. This subjective degree of open-ness (or closed-ness) is intrinsically related to their degree of open-ness (or closed-ness) of sensing and sense-making frames of reference.

The four key aspects of the research gap and the associated contributions made by each of the publications and this thesis are summarised in Table 5-1. The contribution made by this PhD by Published Works is an orders of choice framework that has a two-fold application: first, the explanation of what might shape the nature and scope of a subject's options for choice, termed 'choose-ables'; second, a way of formally appreciating the implications of those choose-ables for a subject's sensing and sense-making; hence their forming of their subjective potential for choice-making and thence any emergent behaviours.

The thesis presents a selection of levels-based, systemic schemes. The 'levels' in these schemes are presented in terms of language or in diagrammatic form, or both. There is no evidence in the academic literature of a nested systemic structure that can offer a formal rigorous framework through which to position subjective-systemic potential and also analyse such potential in terms of possible emergent behaviours; also that offers the possibility of linking it eventually to explanatory, more holistic, models of systems behaviour. This has long been a vision in General Systems Theory (Bertalanffy, 1969; Churchman, 1971), as had been studied previously by academics and practitioners looking for a formal way to 'model' holistically (Smuts, 1926) and systemically (Angyal, 1941).

Table 5-1: Contributions made by the publications to key aspects of the research gap

Research gap aspect	**Publication**	**Contribution against aspect of research gap**
Addressing subjective choice-making and choose-ables rather than objective decision-making and choice selection	Publication 1 Publication 2	Findings that subjective preferences shape choice Catastrophe Theory as a regulatory framework
Addressing 'where a subject is' in terms of their choice-making potential and their open-ness of sensing and sense-making	Publication 4 Publication 6	A nested orders of agility framework A Staged Appreciation
Rigorous theory-based framework for choice-making and scope of choose-ables	Publication 3 Publication 5 Publication 7	A linked Catastrophe-Cultural theory of choice Multi-perspective analytical framework A linking of key theories (see Chapter 2, Section 2.9, Figure 2-4)
Holistic framework to relate a subject's choice potential set across natures of choose-ables	This thesis	A nested orders of choice framework based on a synthesis of the experimental and theoretical contributions across all seven publications.

The various schemes of orders, or levels, covered in the review of the literature have emerged from a variety of disciplines and domains, including General Systems Theory, human and organisational developmental studies, and anthropology. This generality suggests a kind of generative depth of changing relations that can run through aspects of a subject's choices and, in particular, of choice-making. This thesis proposes that it is useful to focus on those changing relations that might shape choose-ables, such that the relational shape-changing creates the potential (at varying orders of choice) for eventual emergent observable forms. The orders of choice are proposed as a useful classification scheme that can then provide a more formal mathematical basis for other levels-based schemes. It does not take the matter of potential any further and so does not make any propositions about any specific resultant behaviours that may come about.

The orders of choice framework is based on the established topology and mathematics of Catastrophe Theory. It is important to note that the catastrophe models are *potential* functions and the main point of this thesis is that it is a study of subjective potential for choice-making rather than being about objective decision-making. Catastrophe Theory, historically, has been applied to biology (Thom, 1975) and physics (Poston and Stewart, 1978). Where Catastrophe Theory has been applied to social and behavioural situations (Smith, 1980; Cobb, 1981), the application has been systematic and aimed at modelling chronos-time-based differentials for dynamic behaviours based on specific catastrophe models (Woodcock and Poston, 1974), usually the cusp catastrophe model (Woodcock and Dockery, 1993) and sometimes the butterfly model as in Zeeman's (1977) application to anorexia nervosa. The models tend therefore to be applied, as appropriate for the modelling of the situation at hand, according to the nature of the general behaviour being manifested and analysed.

The Catastrophe models are based on a principle of finding invariant regions or 'settling' points or minima, which are represented by output-variable 'roots', denoted by 'x' and 'y' in the equations in Chapter 2, Section 2.6, Table 2-4. It should be noted here that the traditional use of these models is to address system outputs such as observable system behaviours. Fararo (1978; p315) remarks that:

> *"predictions about 'x' as a function of the observed trajectory of (a,b) points….would appear to be highly falsifiable. Do we really know how to identify a catastrophe event with such data?"*

This thesis is about choice-making and choose-ables and so the catastrophe models are being approached in a different way such that the variables represent choice potential (i.e. choose-ables) rather than observed output behaviours. This is a subtle but important distinction because herein lies an important aspect of the novelty in this PhD study.

The previous academic focus on the cusp catastrophe model to predict behaviours has meant that the dynamics of the normal factor and the splitting factor (denoted by 'a' and 'b' in Table 2-4 in Chapter 2, Section 2.6) tend to have taken precedence, so the cusp model is treated in isolation with no reference being made to the open-ness and the subjective positioning nature of the outer choose-ables (as shown in Figure 1-1). This indicates the importance of two areas of novelty in this PhD study such that different forms of time hold across the layers, and that the catastrophe models are necessarily nested. The *nested* orders of choice framework provides a way to access the catastrophe models more holistically in relation to a subject's potential for choice-making. The nested structural logic of the catastrophe models, as they relate to the orders of choice, takes a systemic and relational stance that sees the seven catastrophe models 'as a whole'. This now gives studies of systemic potential (e.g. pertaining to a subject's possible behaviours) a new way to apply an appropriate catastrophe model and now with a clear view of what, in terms of choose-ables, lies within that model 'layer' (i.e. shaping due to the scoping of choose-ables) and what lies outside (i.e. conditioning due to the nature of boundaries).

The mathematics of the nested, catastrophe models provide a formal way to explain and explore a subject's choose-ables and the many ways (i.e. imaginable and deem-able possible by that subject) in which they might be being shaped and formed. The different forms of time across the framework will help analysts to be explicit about the different dynamics at play. There will be some choice-making that is slow and continuous, acting as a silent, potentially transformational, substrate for change from which other structures then have the potential to emerge. The orders of choice framework gives a formal language with which to understand why, then, discontinuous 'tipping points' arise from what appears to be a background of gradual change.

Bohm (1980) discusses the concept of implicate enfolded orders seen as an enfolded *potential* that embodies a potential for unfolding to form an explicate landscape for choice. Morgan (1997; p373) significantly adds substance to a need to represent this as the "logic of the system". What might be chosen and then become explicit as observable behaviour is covered well in the literature; however, what might be being attended to by any subject and why (or why not), has not been covered formally and structurally in the literature to date. Morgan (1997; p227) states that, "unfortunately very little research has as yet been conducted on this topic". The novelty in this thesis lies in the centrality of the subject as the receiver of the realised 'logic of the system' associated with the subject's choose-ables for adopting or working within a concept of value.

Bateson (1972; 2002) also presents an analysis that points more evidentially to the lack of a 'logic of the system'; in particular, that the majority of the decision-making studies are lacking when it comes to structural awareness. This thesis brings to the fore the fact that logical, systemic 'structural awareness' forms through the topologically-related orders of choice setting relational conditions, which shape the choose-ables in the form of potential 'affordances' for choice-making (Bradshaw et al, 2004). It is these potentials for choice-making that further shape a subject's sensing and sense-making of their context due to their capability and their capacity to consider potential ways forward. The combining of the subject and their relationship with their context to shape their affordances can now be formally represented in terms of their nature and scope of choose-ables. This offers the research area of human-machine-AI cognition a structural logic with which to study affordance more formally and mathematically; for example, examining potential for dangerous dissonances when human subjects are in collaboration with machine-based subjects.

Critical Systems Heuristics (Ulrich and Reynolds, 2010) also offers a structured framework to allow systematic analysis, working through an analytical view of a stakeholder-based system (i.e. those involved and those affected). However, the orders of choice framework, created through this study, adds to this by providing a complementary *systemic* structure with which to reason and share understanding about the *potential* for behaviours from the point of view of any, or each, of the subjects, specifically. This is supported through use of the Staged Appreciation 'check-list' (Dodd, 2018a) that begins with the need to address 'where subjects are' relationally, according to their choose-ables and ways of sensing, sense-making, valuing, defining of self and in their dividing-up of their world.

The subjective nature of the subject's capacity for attending to, and also their awareness and feel for, the more silent transformational landscapes, and then for seeing the potential edges and cusps, gives additional novelty to this PhD study. The study has opened up a relatively unexplored area of research based around the sensing and sense-making 'of the beholder', which is further shaped by that subject's delineation of self-within-context as a choose-able that then shapes the open-ness or closed-ness of sensing, and of the frames of reference usable for sense-making.

In summary, the research gap being addressed is the lack of a theory-based framework that describes how deep implicate order extends into subjective context, on which the imaginative potential and the deeming possible of choose-ables depends. Also, that the realised explicate order, in terms of what might be brought, through choice potential, into visible or audible form, may not then subjectively be noticed, attended-to or comprehended. This then leads to the overarching research question that puts the formal mathematical framework of nested catastrophe models into a subjective setting, because what any subject might be sensing, and making sense of, will be being shaped and conditioned by where that subject *is* in terms of their choose-ables.

5.2. Addressing the overarching research question

How then can the seven published works be synthesised to address the overarching research question which asked:

From where might a subject's choose-ables emerge; and how might these choose-ables moderate, or be moderated by, that subject's sense-making and their focus of attention?

The portfolio of seven published works covers the supporting theories and also describes the background experimental work that prompted the development of the framework for orders of choice. This thesis formally links Catastrophe Theory to Shackle's (1976) choose-ables. The seven publications form the foundation for the theory that links 'where subjects are' (in terms of their position in relation to their context and circumstantial conditions) through the subjective concept of natures of choose-ables into Catastrophe Theory. The seven publications take the theory only as far as the valuative order of choice based on the butterfly catastrophe model in Dodd (2011) as it relates to the scope of choose-ables through the connection to Cultural Theory and subjective affordance in Dodd (2018b) in terms of a subject's subordination to others' concepts of value and boundary settings. Dodd (2011) brings Cultural Theory into the dynamical systems setting of Catastrophe Theory, such that differentiation is with respect to choose-ables (according to orders of choice) rather than differentiation with respect to time. This gives a theoretical basis for the *scope* of choose-ables; however, the *nature* of choose-ables then needed to be addressed more formally to take the theory into a more subjective and descriptive language for application across a range of different types of subject. Staged Appreciation in Dodd (2018a) provides a way forward into orders of choice as they relate a subject's affordance to different natures of choose-ables. The capability that a subject has to imagine choices along with their capacity to access certain natures of choose-able depends on the degree of open-ness of their sensing and their frame of reference for their sense-making, which is related to their choose-ables within the different orders of choice. So, the theory of choice is developed into a framework for orders of choice that clarifies the natures of the choose-ables.

The seven-fold framework for orders of choice is applicable to a range of subjects; from agent-based algorithms and cells through to organisations and political institutions. A key assumption is that each subject makes choices according to a principle of discomfort avoidance. Subjective preferences, interests and needs relate to a subject's scoping of their choose-ables, according to a subject's sensing and sense-making of their circumstances. Preservation of a subject's sense of comfort forms the basis for invariance as a central concept of subjective 'settling', which governs the nature of the choose-ables according to where any subject is in relation to their context.

The orders of choice are not in any way an 'ordered' set of choices. They are based on the nature of choose-ables being considered by any subject for the purpose of maintaining a sense of its own viability, stability and avoidance of discomfort. For example, the choose-ables might be concerned with responsive choices, such as moves imaginable and accessible to maintain physical comfort when, say, a subject might sense a change in ambient temperature. Choose-ables could also be concerned with maintaining relational comfort when a subject feels that their inter-relationships might be increasingly unmanageable; here, for example, a possible choose-able might be a choice to make a friend into an enemy. These two examples of choose-ables are dealing with choices of a very different nature and are according to a subject's sensed changes in circumstance that may be being interpreted as impinging on a subject's sense of comfort. It is this multifaceted, multi-layered sense of comfort that a subject is trying to preserve.

As with Shackle's (1976) bases of focus, belief and preference, it is possible to distinguish, conceptually and functionally, a subject's sensing, sense-making and choose-ables; however, it is not easy to make them separable because they are so intricately inter-related and represent the subject as a whole. The nested-ness of the orders of choice therefore is the important feature of the framework. It shows that a subject's scope of choose-ables at any specific order of choice tends to shape and also be shaped by what lies inside, and is conditioned by what lies outside that specific order of choice.

In summary, this thesis covers the subjective and relational nature of what is imaginable and being deemed possible, and also the subjective nature of what is being received, attended-to, noticed and comprehended; to what degree, and according to what kinds of frames of reference, and why.

5.3. Recommendations and challenges for application

The framework of nested orders of choice is based on Catastrophe Theory with further understanding drawn from other, related theories about levels of capability and organisation; it also uses a relational framework in Cultural Theory for the scoping of choose-ables. The usefulness of the orders of choice framework lies in its provision of a formal descriptive language that can be applied in order to understand and appreciate where any subject might be in terms of their choose-ables, and also potentially to explain why.

The seven-fold order of choice framework is aligned to other seven-fold schemes for organisation and capability. This epistemologically develops what is meant by making a choice[64] in order to distinguish it from being a decisive or active option. Choice-making is developed through the incorporation of the subjective concept of choose-ables to mean that choices are being made according to where a subject feels themselves to be in relation to their awareness and understanding of their context. This subjective context, therefore, consists of orders of choice that may or may not be considered to be within a subject's imaginative power; also, the choices may not be deemed by the subject to be open to them for choosing.

The scope of choose-ables, at whatever order and of whatever nature, is then related to, and could be conditioning, the subject's sensing and making sense of their context. The co-development of a basis for understanding conditioning of sensing and sense-making takes place over several years, drawing from direct experience and also from previous experiments with critical decision-makers. A key assumption is that, irrespective of the order of choice, each subject will be making choices according to a principle of discomfort reduction or avoidance (or minimisation) so, the different forms of discomfort tend to be manifested as a need, drive or motivation to address choose-ables at whatever orders of choice are felt to be open and accessible for preservation of that subject's comfort. This is the form that the principle of invariance takes.

The scope of these choose-ables depends on the ways in which the contextual orders (or the lower sections of the iceberg in Chapter 1, Section 1.3, Figure 1-2) build on each other, demonstrating how

[64] Based on the knowledge in the literature relating to these levels-based schemes, choice-making would be taken to be a 'higher-order' form of decision-making that is then distinguished from decision-taking.

they might shape a subject's focus, beliefs or preferences according to their overall sense of discomfort. The 'sub-threshold' layers of the iceberg and the systemic structural logic of the orders of choice provide a formal language for deeper reasoning and for sharing understanding around the dynamics of any subject's potential; now formally expressible in the form of their choose-ables. This formal understanding of subjective potential (due to the nested dynamics of the deeper, unseen and usually un-see-able, regions of choice-making) can now be based on a framework, within which to question resultant observable behaviours as they are happening, or to anticipate and influence behaviours 'ahead of time'.

Indeed, such is the focus of study for units advising government; for instance, as used in the so-called 'nudge' unit that is now called the Behavioural Insights Team[65]; however, they tend still to keep the focus on a behavioural science approach to look at presentation of information and accessibility of reference material that may then 'promote' certain choices being selected rather than others. This is also the approach of other popular authors around people being "citizens of choice-land"[66]. Their discussions about how people 'make choices' is around decision-taking[67]. There is some reference to values being now more 'open to choice' but with no acknowledgement of where people's choose-ables about concepts of value might be coming from or being shaped by.

This then leads to the overarching research question that puts the formal mathematical framework of nested catastrophe models into a subjective setting, because what any subject might be sensing and making sense of will be being shaped and conditioned by where that subject *is* (i.e. feels themselves to be or can be rationalised as being) in terms of their choose-ables.

This last sentence raises a big methodological, philosophical conundrum because of the need to analytically reason about the positioning of a subject in terms of their open-ness to different natures of choose-ables whilst also subjectively needing to adopt that subject's viewpoint, mind-set and standpoint to appreciate what they are taking to be sense-able inputs from their context, which is dependent on the rationalisation of the self-context and self-other boundary choices. Important methodological questions are raised concerning the analytical positioning of the subject. How is this positioning being done and by whom? According to what ontological position(s)? This strongly depends on the reflective capability of the subject doing the analysis; hence the need for a Staged Appreciation check-list to act as a guide (Dodd, 2018a).

The publications supported by this thesis provide a framework to act as a firmer foundation for weaving and working through such a methodological minefield in order that those who need to analyse and understand choice-making can do so:

- Systemically, holistically and relationally to reason about where a subject might be.
- Appreciatively and subjectively to help a subject to reflect on where it is or feels itself to be.

It may help at this final stage to return to the methodological journey in terms of the four key aspects of the research gap. Figure 5-1 shows the four key aspects and the path followed throughout the time

[65] For more detail see https://www.bi.team (accessed October 2019).
[66] See https://www.goodreads.com/book/show/6648865-the-art-of-choosing (accessed October 2019).
[67] Dodd and Markham (2013) give a distinction between decision-*taking* and decision-*making.*

of the study, as charted by the publications. The outcome of this journey is shown in the centre to be an understanding of a subject's potential for choice-making (i.e. their capacity for choice and their capability to imagine) that can then be worked back through into the supporting levels-based schemes to be applied to: people in organisations (Jaques et al, 1978); General Systems Theory (Boulding, 1956); viable organisations (Beer, 1995); ways of organising (Morgan, 1997); levels of capability (Isaac and O-Conner, 1976; Stamp, 1989); imaginative, subjective potential for choice-making (Shackle, 1986). Reflecting on the journey through the publications charted in Figure 5-1, the methodological stance has necessarily shifted along the way. Initially subjective choice-making was a surprising result from an hypothesis-driven decision-making experiment that was then explored theoretically through a regulatory framework to explain the differences in participants' foci of attention and utility functions. Differences in cultural evaluation of projected outcomes then prompted development of the theory.

The differences in perspective, based on what matters to a subject (i.e. a subject's ways of appreciating others' concept of value), developed the objective view of choice theory into a multi-perspective study where relationships between subjects became important in terms of shaping the subjective context. It is at this point that the ontological position shifts away from reference to a situational realism to be about a context being constructed on the basis of many different perspectives. At this stage, the choose-ables are seen only in terms of scope and so are taken to be responsive actions. Now the focus has to turn to shine a reflective light on the researcher or analyst so that they can appreciate that their perspective is only one of many and that it is founded in their focus of attention, their belief-models used for sense-making and their choose-ables. It is now that the nature of choose-ables returns as a shaper of the sensing and sense-making. The scope of the choose-ables then is re-examined through the different cultural frames and an extension of affordance that adopts a more subjective contextual stance than the usual treatment of environmental affordance. This thesis draws all of these different methodological approaches together to position the overarching research question as a carefully worded question that encourages open-ness of mind, reflectivity and a relational subjective approach to choice-making.

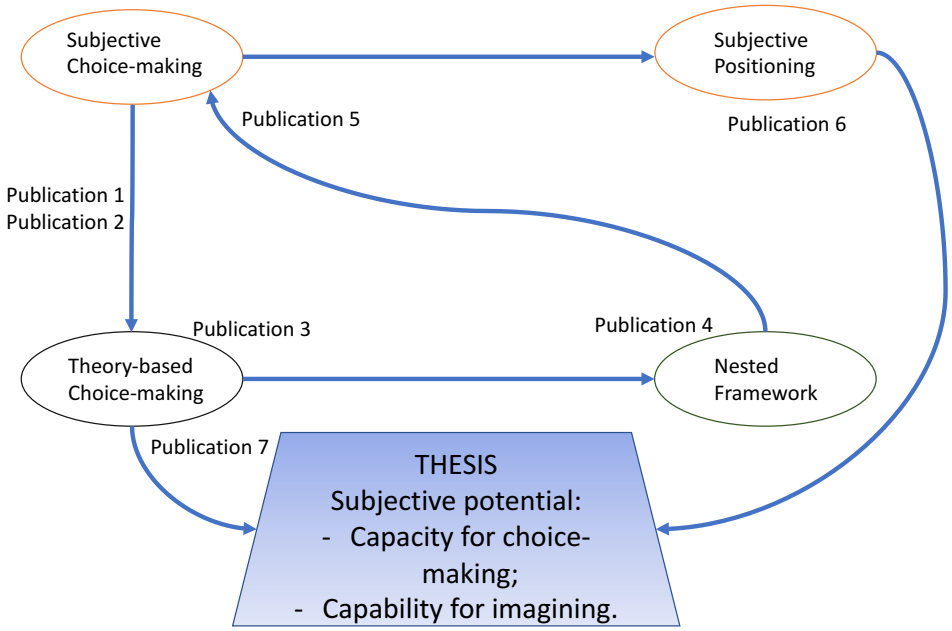

Figure 5-1: The research journey as it visits the four aspects of the research gap (Source: Author)

5.4. Avenues for further work

The seven publications develop choice-making theory based on only the cuspoid catastrophe models. This thesis then proposes ways in which the umbilic catastrophe models could be taken to represent the self-boundary, self-other and divisive orders of choice, due to there being two dependent variables in the umbilics rather than a single variable in the cuspoids. This extension of the theory now needs to be studied more formally. The only apparent source of application of the umbilic catastrophe models to socio-political areas is in Guastello's (1995) work, which discusses empirical studies on social and organisational behaviour covering stress, motivation, risk, creative problem solving and organisational leadership challenges. Guastello (1995; pp83-86) refers to the umbilics as "wave crest" and "hair and mushroom". He also points to intriguing ways to interpret the hyperbolic umbilic (i.e. wave crest) catastrophe model:

> "*The relationship that is explored between the complex lag functions and the wave crest thus opens an important window to coupled dynamics such as those that occur in self-organized systems*" Guastello (1995; p86).

This reinforces the importance of studying the link between forms of time, complexity (in terms of intricacy of couplings) and organisation as it relates to self. It is made clear through this thesis that the orders of choice framework has been developed with reference to all of these key aspects.

In addition to furthering study into complex dynamics and self-organisation, there is now interest in Systems Leadership (Macdonald et al, 2018), which identifies a particular need for formal frameworks

to address strategic choice-making. Interestingly and relevantly, Guastello (1995; p302) extends Stacey's (1992) work on creative strategic leadership through exploration of the parabolic umbilic catastrophe model:

> "*To develop a high-dimensional mushroom catastrophe model for creative output. The mushroom structure is observed in creative output through the curiously shaped frequency distribution.*"

It is through such applications to strategic leadership studies (Stacey, 1996; Wheatley, 1992) that the orders of choice framework can give a formal systemic structure through which to develop ways of working and thinking, systemically and holistically, that are now being seen as requirements as senior leaders face increasingly complex challenges, as evidenced by the recent establishment of the UK National Leadership Centre[68].

A further area of study follows an avenue discussed in Publication 7 (Dodd, 2018b) that relates to the associations of this thesis's choice-making theory with Drama Theory (Bennett et al, 2001). Drama Theory looks mainly at actors' options as cards that the different actors may have at their disposal to play, threaten, hold close to their chest, keep as fall-back options, etc. It developed alongside Confrontation Analysis (Howard, 2011) which stands as a reminder that conflict tends to emerge through shifts in underlying relational conflict, conditioned by means and ways of communication[69]. Now that the framework for orders of choice has a formal mathematical basis, it is possible to return to these areas of research to extend, for example, Drama Theory to look beyond the scope of a subject's choose-ables into rationales for a subject's nature of choose-ables being at the heart of any subject-to-subject confrontation, hence the potential for conflict or reactionary behaviour.

It has been suggested by colleagues that the orders of choice framework, linked more formally with Stamp's (1990) levels, could use Shakespeare's plays to illustrate how this PhD study has synthesised Drama Theory, Cultural Theory, Catastrophe Theory and Choice Theory. This avenue for further study will help to make the theory come to life and make it more accessible through reference to stories based on people, culture, society and power.

5.5. A return to Reflective Practice

As discussed in Chapter 1 Section 1.1 the orders of choice framework has been developed while the author has been involved educationally in Reflective Practice; in particular, working with people as they share their different perspectives and their different ways of making sense of messy problems. Each person, as a sensing, sense-making and choice-making subject, comes to a problematic situation in their own way that is shaped by their preferences and beliefs (expressed through their choose-ables as their imaginable and deemed possible 'solutions to the problem'). As an educator in Reflective Practice, the orders of choice framework provides understanding of the people being educated (and that always includes me). To date the author has only used the framework informally as it has been intuitively developed and now made more formal through the application of the Catastrophe models.

[68] See https://www.nationalleadership.gov.uk (accessed November 2019)

[69] Again here, as stated in Chapter 2, Section 2-5, communication refers to what is going on between subjects, and subject's contexts (Luhmann, 1996) rather than being about transmitting and receiving information across networks.

As a final illustrative example of how the framework can be used, here is a 'worked example' using Staged Appreciation (Dodd, 2018a) as a guide to show the way that an educator can appreciate the sensing, sense-making, and choice-making perspective of any subject as they are being educated in Reflective Practice.

Stage 1: Where a person is. Their ways of dividing-up their world (e.g. do they talk in terms of 'us and them'?); How they define themselves in relation to others?; Can they readily step into another person's 'shoes' or mind-set?; Do they find it difficult to consider their own perspective alongside the different perspectives of others? These questions are working inwards, starting from the outside layer of the framework, understanding the divisive and self-other orders of choice.

Stage 2: Understanding a person's way of representing their beliefs about the future and how they think about surprise. Do they find comfort in thinking that they can predict the future? Are they comfortable with openly considering a wide range of possible futures? Can they grasp that surprise is directly related to their own personal beliefs and expectations? These questions are working to understand the prospective order of choice.

Stage 3: Where they are in the OE:OM matrix with some reasoning about why? Is there a sense of discomfort when dealing with unusual events[70]? What do they take a 'black swan' to mean? Are they able to reflect at all about where *they* might 'sit' in the OE/OM matrix in terms of their comfort-zone? This reflective aspect of sense-making extends into the making of meaning[71], which is personally and subjectively deeper than sense-making. These questions are working to understanding the variative order of choice for that person as they come to reflective practice.

Stage 4: Their preferences and nature of their choose-ables. What does it mean for things to be working well for them? What are their preferred ways of working? Is the nature of their choose-ables only about taking action or do they consider choose-ables that are about ways of organising, or thinking ahead, or considering different ways of seeing? These questions are working to help them to appreciate their own concept of value based at the important, challenging valuative order of choice.

Stage 5: Their responses to choice-making. How do they react to techniques[72] that demand creative thinking and open attitudes to new ways forward? Is there a natural tendency to explore "why else?" and especially "how else?" might we…? Or, is there a resistance to opening-up and moving outside of the 'business as usual' ways of working? These questions are understanding their overall willingness to reflect on their natures of choose-ables so is addressing their open-ness to appreciating orders of choice more generally.

Stage 6: How they respond to multi-perspectives. Are they able to stand in other people's 'shoes' and can they readily take off their own shoes first? Do they feel comfortable imagining another concept of value (e.g. asking a counter-terrorism specialist to adopt the values of a terrorist)? What matters to them? Can they appreciate what matters to other people (Dodd and Alston, 2009)? These questions

[70] Marris (1982) describes this discomfort as a discontinuity that occurs when a person's relationship structure is disrupted, which then requires considerable effort to rebuild structures of meaning and to restore balance.
[71] "The concept of meaning relates the unique experience of each individual to the structure of social relationships." (Marris, 1982, pi).
[72] One example here is the Ladder of Abstraction technique discussed in Dodd (2018a).

are working to open-up and understand the valuative, self, self-other orders of choice and to bring people to the personally challenging divisive order of choice.

This offers a framework for making sense of people as they work through reflective practice education, which can often be extremely challenging for them as the journey is always across a discontinuity.

5.6. Final Reflections on Wholeness

The references to Bohm's work in Chapter 1, Section 1.2 and Chapter 2, Section 2.5 now need to be returned to more reflectively, as this thesis speaks to wholeness and the enduring questions surrounding quantum theory. These questions were upheld and sustained by Bohm as his work on hidden variables[73] (Bohm and Hiley, 1982) was brought to life in a simulation of 'pilot waves' (Hiley, 1995) such that the choice-shaping landscape could be imagined. Bohm's (1980) concept of implicate enfolded orders can be seen as unfolding to form a landscape for choice-making. The concept of implicate enfolded orders can be taken to be an enfolded *potential* that embodies a potential for unfolding to form an explicate subjective landscape for choice-making. The topological conditioning of an enfolded *potential* for choice can be formally described according to a nested integration, or synthesis, of orders of choice. The topological forms, within each order of choice, can describe impacts on choice potential due to adaptation in relational conditions to maintain a subject's sense of comfort in their sensing and their sense-making. These relational conditions then shape the scope of choices available, by whatever or whomever might be making a choice and also what might be affected by the changing relations. The structural determinism assumed here is in the form of relational conditioning of choose-ables be-coming so that, ultimately, choose-ables shape the potential ways in which any subject (be it a cell, an electron, an individual, an institution) might 'be-have'. Therefore, it is suggested here finally that the potential for choice-making enfolded in the subjective, relative orders of choice framework, represented by the Catastrophe models[74], might provide an embodiment of that shaping landscape. The depth of changing relations that runs through aspects of choice then conditions a subject's choice-making, which in turn forms the frames of reference for a subject's sense-making. This thesis proposes that it is these unfolding subjectively-formed relations that shape a subject's choose-ables, such that the shape-changing dynamics create a kind of adaptive potential for emergent, eventual observable forms and behaviours, working through the subject's ways of sensing and of sense-making.

[73] Bohm had published a paper on hidden variables in 1952 but it was dismissed by prominent physicists; however, this work related to de Broglie's 1927 work on pilot waves that was also abandoned. Their ideas were based on a hidden, variable enfolded guiding landscape that somehow governed a particle's trajectory.
[74] Arnold (1992) suggests that these may not be limited to seven and he goes on in later years to extend the thinking around bifurcations and singularities into new forms of classifications based on inter-lacing.

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Annex: Portfolio of Publications and Co-author Contribution Statements

The annex presents the full published versions of the seven publications that make up the portfolio that stands as the central basis for this PhD study. Some of the publications contained specifically detailed and specially type-set mathematics that could not be readily re-worked into a Microsoft Word document format. It is for this reason that the full portfolio has been presented in an annex rather than forming the main part of the thesis. Chapter 4 does, however, give summarised details of the key sections of the seven publications that contribute directly to the PhD study narrative.

Finally, the statements from each co-author are also presented to confirm my contribution for each of the four co-authored publications in the portfolio and to support the originality of this PhD study.

Discontinuity in decision-making when objectives conflict: a military command decision case study.

Lorraine Dodd[1], Prof Jim Moffat[2], Prof Jim Smith[3]

Abstract

In previous work, we have considered the representation of the human decision-making process in closed form simulation models of conflict. An important element of this representation is the Rapid Planning process that embodies the processing of information for situation assessment to support a course of action decision (for example in a military headquarters).

This paper describes the application of non-linear multi-attribute utility theory in conflict scenarios in order to extend the representation of the Rapid Planning process to account for a wider set of subjective attributes of the decision-maker. The results show, through examination of experimental data, that decision-making can be modelled through a particular class of utility functions. These utilities embody a geometry which is qualitatively stable and which allows us to classify the types of decision being made when there are conflicting objectives and when decision-makers adopt very different and subjective appraisals of constraints and beliefs in outcome. The experimental results show that the subjective nature of the situation assessment, and the personality, training, experience and history of the decision-maker are central to the functional representations. The paper presents a way to capture this deeper representation of human decision-making in a way that is potentially useful for quantitative modelling using the Rapid Planning process as a basis.

1. Background

For high level balance of investment analysis, the individual psychology of the decision maker(s) represented in the models is not (and should not be) a key driver. However, at the systems level (in particular for Command Information Systems), it becomes a much more important issue because it is difficult to address the design of command information systems (CIS) without a formal representation of the human decision processes that the CIS will support. Systems procurement decisions are generally supported by analysis that uses constructive simulations but these tend to contain simplified representations of Command and Control (C2) decision-making. This paper offers a theory that provides a framework for representing C2 decision-making in situations of threat, uncertainty and conflicting objectives. The framework will aid the formal definition of C2 conceptual models that are central to the development of CIS within Network Enabled Capability; for example, the difference between shared awareness and shared understanding.

2. Introduction

[1] Intelligence Systems, Room 222 Turing Building, QinetiQ, St Andrews Rd, Malvern WR14 3PS
[2] PCS Dept, A3 Building, Defence Science and Technology Laboratory (Dstl), Farnborough, GU14 0LX
[3] Statistics Dept, University of Warwick, Coventry, CV4 7AL

A new approach to the representation of Military Command and Control in fast-running, high-level constructive simulation models has been developed [1,2] and is currently being incorporated into a new generation of simulation models with Command and Control (C2) at their core. The emergent combat behaviour produced by these C2 agents has been validated by comparison with historical conflicts [3]. As part of this set of ideas, the Rapid Planning approach has been developed, which represents the decision-making process of experts under uncertainty, working in fast and fluid circumstances and as part of a C2 decision-making network or hierarchy. The Rapid Planning process firstly defines the set of key situational-information attributes that the decision-maker uses to 'frame' his problem domain [4]. These define a space that we can call the C2 'decision space'. Dynamic Linear Models (DLM) [5] are then used to assess the significance of any changes in these key information attributes over time. The decision-maker defines particular areas of the decision space where he places particular emphasis, and for which he has an understanding of the potential consequences of his courses of action. The process of pattern matching lies at the heart of the approach. This matching is done between the decision-maker's assessment of where he currently is in the space (as defined by the DLM) and the areas of emphasis in the space that are associated with potential courses of action. The DLM approach is Bayesian in nature and is driven by incoming information and subjective priors. The DLM approach has been extended to include a further set of factors that drive the C2 decision process [6,7,8,9] based on non-linear utility theory [10,11,12] that try to explain, by decomposition, the subjective variability in C2 course of action selection. The factors account for adjustments in the attributes and adaptation of the areas of emphasis to accommodate the decision-makers' sense of "comfort" with regard to the courses of action.

3. Overview

Section 4 introduces the non-linear theory by briefly reporting the initial application of the theory to explore the discontinuous nature of command decision-making. Section 5 discusses Recognition Primed Decision-making (RPD), which is the foundation for the Rapid Planning approach, and sets the scene for the experimental game. Sections 6 and 7 describe the two settings for the experimental game and present the results using twenty-four military commanders, aiming to illustrate and test the theory. Section 8 explains the theory of non-linear utility and the geometry of competing objectives, using the peace-support example as an illustration. Section 9 presents the conclusions drawn from the experimental results and recommends how the formalisms we have developed may be used to understand command decision-making performance in typical conflict situations to aid future design of CIS, communication protocols and training strategies.

4. Rapid Planning and non-linear utility

The Rapid Planning process was initially extended to represent, as distribution functions, the decision-maker's belief in future outcomes and his subjective evaluation of the losses associated with these potential outcomes. When the belief and loss functions are combined to give an expected loss function, it results in minima that relate to the local and global decision options. (Note that loss is negative utility; minimising loss corresponds to maximising utility). Changes in the beliefs in outcome and the loss values (due to changes in situation uncertainty, on-going operational activity or operational context) cause a change in balance between the two minima [6]. This extension has been incorporated into the Rapid Planning algorithm to indicate whether or not the local commander should

deviate from his current course of action (CoA). There was, however, a particular problem associated with evaluation of a commander's loss function, as viewed from the perspective of his own local command and that of his superior command. Initial examination of the results of the command decision-making experiment showed that these subjective evaluations should be represented in terms of utility and that they are composed of assessments of decision outcomes from different mission-objective perspectives. This has led us towards a further extension into non-linear utility theory that allows us to explain why CoA selections differ qualitatively dependent on the decision-makers' experiences and preferences, as these are expressed in the parameters of their subjective probability densities and utility functions. It may then be possible to understand with more clarity and formal definition:

a) How the objective inputs (based on in-coming information) and the subjective inputs (based on an individual's training, experience and personality) combine in the decision making process.
b) How considerations of utility (from the different perspectives) influence this process; in particular, when there are conflicting local and global values within the C2 decision-making structure.

At each level in the C2 structure, the mission statements, orders and rules of engagement must be interpreted by the commander and accommodated into his subjective utility attributes, with criteria weights which hopefully represent C2 priorities, at least approximately. The missions described in this paper are simplified to just two levels of attributes, although general theory is not limited to two levels. The first attribute measures the local outcome of the mission in terms of shorter-term, lower-order considerations (such as loss of life). The second attribute measures longer-term and more global concerns related to higher-order considerations (for example, integrity of the NATO campaign). The analysis sets out a formal reasoning about a decision process when a commander's response to his local situation may be inappropriate from the perspective of higher-level command, and it describes how this tension between local and more global concerns can be formally modelled.

The choice of course of action depends on the interpretation of mission orders (i.e. weighing of priorities in terms of utilities) and the subjective situation assessment (i.e. weighing of evidence derived from subjective informational attributes). The commander may be unable simultaneously to reconcile, even partially, the objectives associated with the attributes pertaining to the high-level mission objectives and his own local appreciation of immediate potential threat. When this happens he may be forced to choose an action that focuses on local, shorter-term success, marginalising the longer-term implications of his action. Alternatively, he may place more weight on global concerns. This tension between objectives is the basis for the derivation of the subjective utility and depends on the subjective descriptors of the conflict situation, the interpretation of the mission orders and the general appreciation of the situation. The relative importance each commander places on the local and global objectives is central to a conceptual understanding of "value" in decision-making. It seems that such qualitative relationships are enduring in this context and that they provide a useful framework for C2 modelling.

In practice, most Bayesian decision analyses usually begin by assuming that the decision-maker's utility function, U, has associated with it a set of value-independent "situation" attributes x_i [13]. In our application, these attributes are associated with situation features

that are immediately local to the decision-maker (x_1) and those that have a longer-term, more global impact (x_2). The parameters that form the shape of the utility functions U_i relative to these goal attributes are denoted by $\beta_i(\lambda_1)$. For a decision, d, a decision-maker's utility function has to capture the trade-off between the different goals by assigning weights, $\alpha(\lambda_1) = (\alpha_1(\lambda_1), \alpha_2(\lambda_1))$, to reflect the importance of achieving the desired values of the attributes, whose achievement is evaluated by the utilities.

His beliefs about future values of the attributes are represented by a probability function $p_i(\theta_i \mid d,\lambda_2)$ which is the decision-maker's current (subjective) probability of outcome θ_i relative to goal attribute x_i, given decision d where λ_2 is a shape parameter for this probability distribution.

The decision-maker should thus choose d to maximise the expectation of $U(d,\lambda_1)$ (averaging over his beliefs about different outcomes θ_i and their utilities). The decision-maker has a free choice of how to set $\alpha(\lambda_1)$ reflecting, for instance, his priorities and ambitions and even his fears. In most military settings a decision-maker will be acting within a C2 structure and will be held accountable for his chosen course of action d. It is therefore reasonable to expect that the specific nature of the mission objectives and the previously absorbed general training and personal history will be reflected in the commander's choice of $\alpha(\lambda_1)$.

Note that the densities $p_i(\theta_i \mid d,\lambda_2)$ can only, at best, approximate a commander's estimate of attribute values against his general beliefs about future outcomes. His information will be imperfect and incomplete. Resources in the HQ to process the available information will be limited and subject to mistakes through lack of training, expertise and failure to follow procedure or just lack of imagination. A formal representation of the CIS within the HQ is outside the scope of this work; however, related work on CIS entropy and plecticity [4] will help to form the necessary conceptual link. It is nonetheless useful to maintain the formality of the theory at this point as this enables us to address what the consequences might be of C2 decisions in an idealized framework, which can later be relaxed. A similar formal utility-based approach is taken in [14].

5. Recognition-Primed Decision-Making and the experimental game

One part of a UK Ministry of Defence research programme to investigate the "Contribution of the Human Element to Command Effectiveness" used a Recognition-Primed Decision-making (RPD) experimental game to examine the hypothesis that course of action (CoA) selection is a direct consequence of pattern matching. RPD [15] describes how experienced practitioners, under uncertainty and stress, make decisions in their domain of expertise. It consists of three phases: situation recognition, serial course of action evaluation and mental simulation. Situation recognition in the presence of plausible goals leads to the selection of appropriate action with little or no search through alternatives. Serial course of action evaluation is undertaken only if the first feasible course of action is rejected. Mental simulation is the process used to evaluate actions (serially) if course of action evaluation is necessary. (See [16] for details of previous experiments.)

A key feature of the RPD model is the idea that decision-makers recognise the situation by matching the pattern of cues and indicators, contained in presented information, to previous situations remembered from past experiences. This recognition process provides access to pre-learned knowledge about how "best" to behave and what to expect in such a situation. This pre-learned knowledge shapes the decision-maker's process of situation assessment and provides the starting point for course of action generation. In terms of the Rapid Planning process, this relates to the subjectively pre-specified areas of the decision space on which the decision-maker places emphasis. It also relates to how he then maps one of these areas onto a preferred course of action. The overall process is then:

1. To identify where you are in the decision space (based on tracking the values of the key information attributes over time);
2. To assess which of the pre-specified areas of the space the track pertains to (the pattern matching process);
3. To map, from that identification, onto a preferred course of action.

The RPD game was thus designed to measure the predisposition of participants, in a situation in which they should be experts, by requiring them to make a rapid determination of a course of action. Participants were presented with an initial operational picture and situation brief. They then had about ten minutes to appraise the situation. Then an Intelligence report was briefed which might (or might not) demand action. The participants were then asked to choose and write down a course of action without being given any further time for analysis. The Intelligence update was designed to give them some room for choosing different courses of action so that their pre-dispositions were allowed to surface as variations in choice.

After the course of action was selected, participants were invited to record their situation appraisal and assessments along with the key indicators considered relevant to their course of action choice. It was accepted that this data might reflect post-hoc rationalisation to some extent. To account for any changes in situation assessment due to the process of having to analyse and express it, the participants were also offered the opportunity to record any other courses of action that they may have considered.

The RPD experimental game results give us a context within which to explore and test the non-linear utility theory. It appears that the extent to which each attribute is (or is not) considered in the pattern-matching process strongly determines the choice of course of action. The RPD experimental game was based around C2 decisions at Battle Group and Company levels set in two different conflict scenarios: war-fighting and peace-support.

6. War-fighting scenario

The war-fighting RPD game was played after participants had taken part in a related Brigade-level planning exercise, which provided them with a good appreciation of the operational context. The participants were focused on a decision concerning a Battle Group (BG) of three tank Companies located in hides on a large wooded ridge feature called Elfas (top middle-left in Figure 1). Enemy armoured and mechanised units could be seen travelling along roads either side of the ridge. The Brigade mission was to delay the enemy advance for twenty-four hours until bridges to the West could be secured. A full written brief was presented that described the current operational status of all units within the Brigade area of interest. Then followed a situation update as depicted in Figure 1.

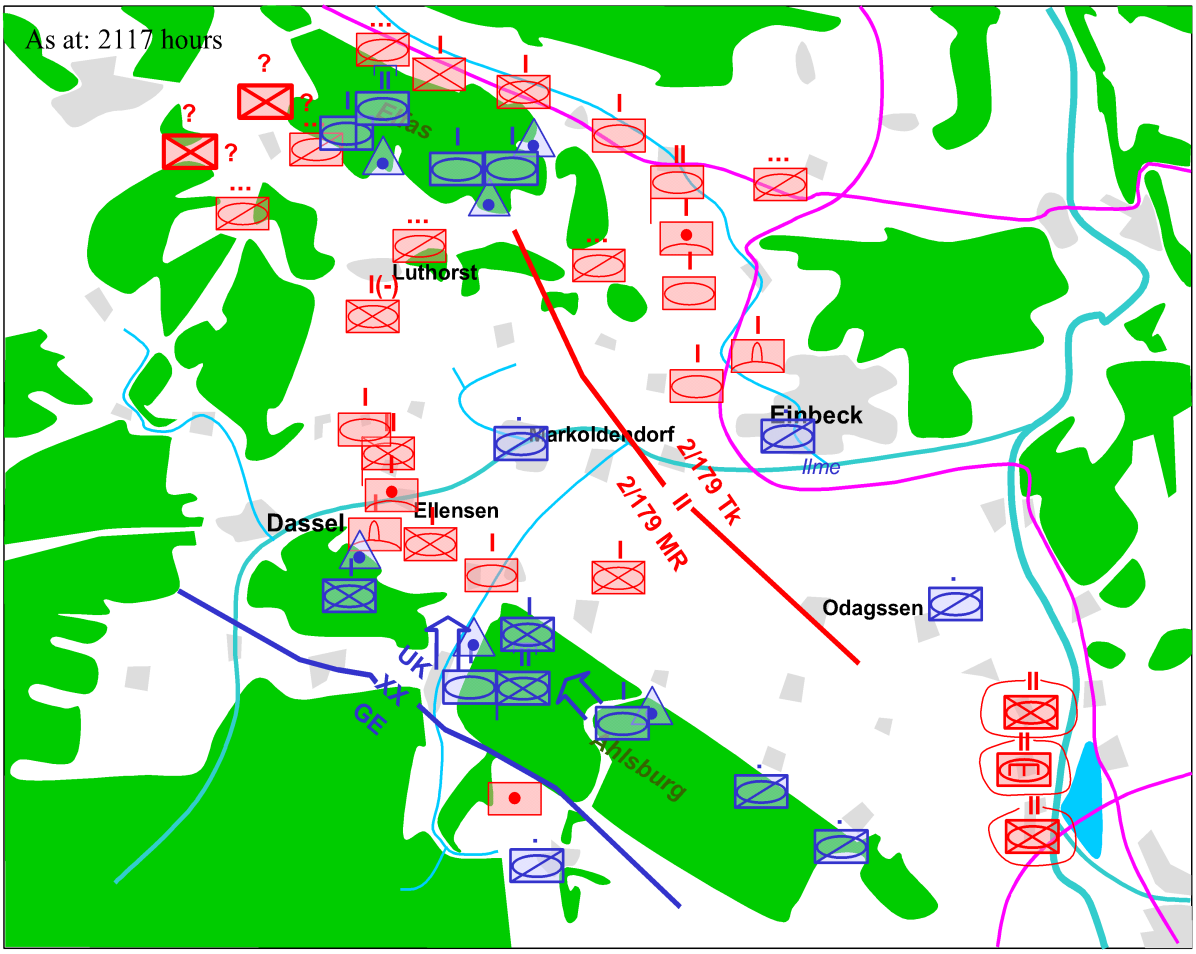

Figure 1: schematic map of the situation update

The situation update indicates probable enemy airborne deployments to the West of the Elfas feature. The strength of these deployments is not known but is assessed as Company(+). The participants were asked to write down immediately their course of action. As the BG commander in the field HQ there are several courses of action available, for example:

- remain in hides and do nothing;
- request more information;
- attack North/North-East (hoping for surprise) against the armoured enemy units;
- attack West directly against the reported deployment of airborne troops;
- maintain a South-east withdrawal route to join-up with own forces.

The CoA choices across the twenty-four participants appear to vary according to the way that they have taken account of the situation attributes and the higher-level mission orders. Some participants choose to give very little (if no) weight to the higher-level mission orders and focus on achieving effects that satisfy local utility. This local view of the mission in some cases tends to extend to the use and interpretation of the situation attributes in terms of both space and time. So, for example, the situation may be appraised purely as a snapshot in time (i.e. little or no forward projection) thus decision outcomes are assessed only from the point of view of the BG, ignoring the overall Brigade mission.

Table 1 shows the association of the weighted utility values and attributes with the selected course of action. The utility values indicate a need to initiate an active decision to move out of Elfas hides to attack but this can be qualified and delayed if there is uncertainty. This draws out that there are two concurrent, inter-dependent assessment processes: threat assessment and risk assessment. For those participants who are not so concerned about the uncertainty in the situation update, the relative weightings on the BG and Brigade mission priorities coupled with the practical consideration of employing tanks against dismounted airborne troops, result in two very different courses of action. Some chose to attack West (employing tanks against dismounted troops and preventing link-up and closure of the gap West of Luthorst) and while others chose to attack North/N-East using tanks against tanks and adhering to Brigade orders.

BattleGrp Mission $\alpha_1(\lambda_1)$	Brigade mission $\alpha_2(\lambda_1)$	BattleGrp Utility $U_1(d,\beta_1(\lambda_1))$	Brigade Utility $U_2(d,\beta_2(\lambda_1))$	Situation Certainty λ_2	Matched Assets x_1	Course of Action Selected
High	Low	Prevent gap closure		Certain	Not Considered	Attack West
Low	High		Disrupt & delay main Bde threat	Certain	Attack like with like	Attack North/N-East
High	Low	Cover gap		Uncertain	Not Considered	Recce Prepare for West
Medium	Medium	Local threat		Certain Snapshot	Not Considered	Limited West
High-Medium	Low-Medium	Encircled Enveloped		Uncertain	Unsuitable Assets	East or South
High	Low	Not critical	Not critical	Certain	Unsuitable Assets	Prepare Artillery and recce
High	Low	Not critical	Not critical	Uncertain	Unsuitable Assets	Recce & report to Brigade

Table 1: Utilities, attributes and CoAs for the warfighting scenario.

Where there is uncertainty and lack of confidence, the participants choose to keep tanks in reserve or prepare for attack while doing further reconnaissance; or secure a withdrawal route to rejoin the southern BG; or simply do nothing, remain in hides and report to Brigade.

7. Peace-support scenario

The peace-support scenario is set in a fictitious federation and involves provision of armed support for conveyance of supplies and civilians to and from a NATO-protected enclave East of the 'Nettoyer Pass' (Figures 2a and 2b). Following the break-up of the federation, the two major factions have been left in a state of armed stand-off. The NATO Task Force, with the UK acting as the lead nation, is a Division-sized force with a task of disarming the ethnic militia. NATO forces also have undertaken to escort and protect all aid convoys. The broader NATO mission is to restore peace and stability to the area in order to create the conditions for a free vote by the population on the future of the region.

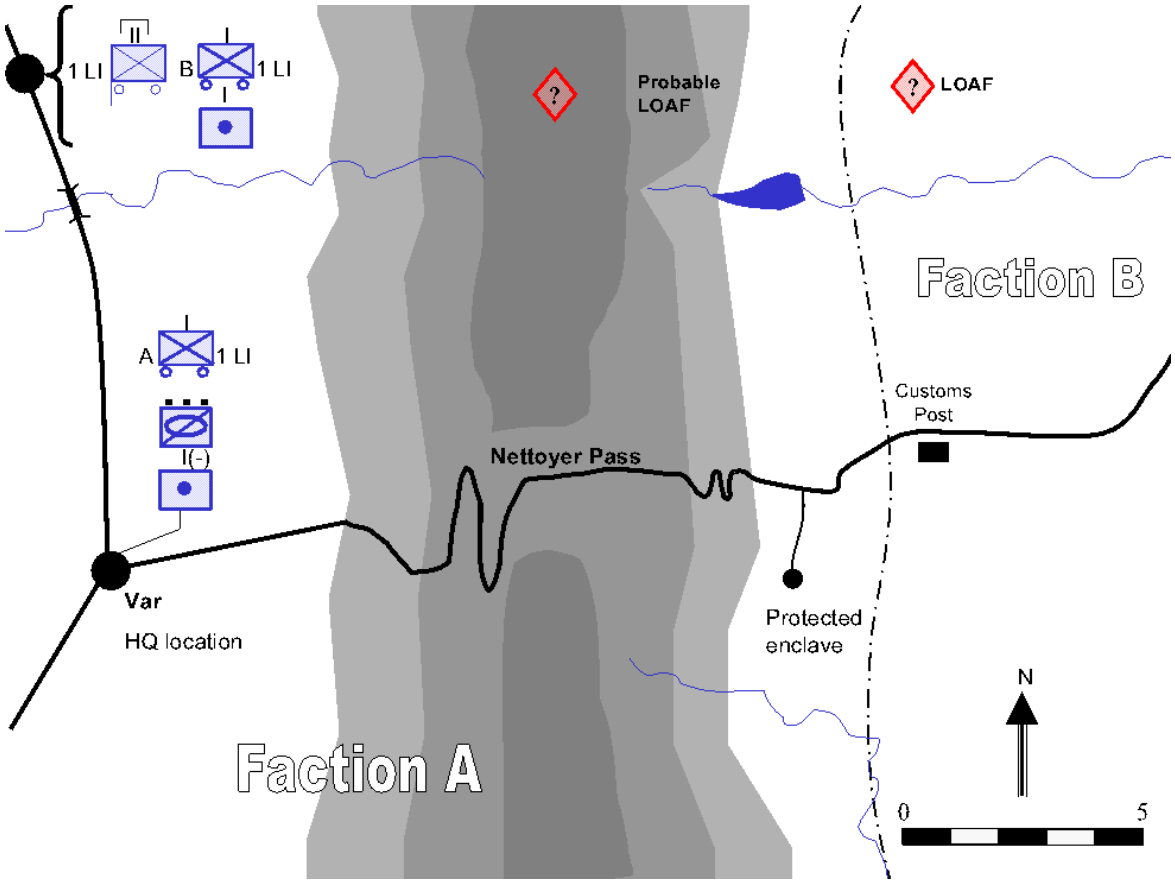

Figure 2a: Peace Support Situation overview

The Intelligence update (depicted in Figure 2b) is sent to the tactical commander in the form of a radio message from an armed unit with two land rovers escorting a civilian relief convoy of six vehicles. The armed convoy has been stopped at a probable Illegal Vehicle Control Point (IVCP) in a mountain pass as it returns from delivering supplies to the enclave.

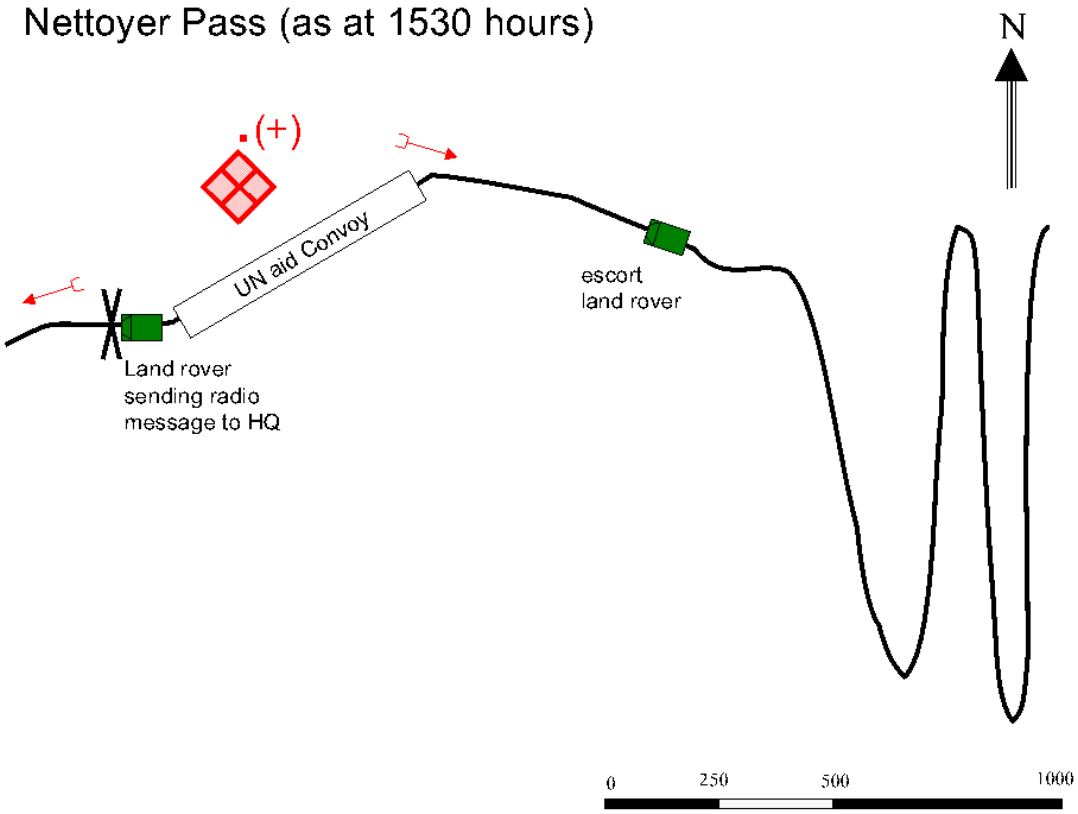

Figure 2b: Situation close-up and situation update

The IVCP consists of twelve men, armed with AK-47 assault rifles and at least two RPG-7's. The second escort Land Rover is 500m to the rear of the convoy. We focus here on the decision-making of the commander back at the field HQ located at Var (see Figure 2a). There are several courses of action available; for example:

- order the UK troops to negotiate their way out of the situation;
- order a withdrawal to move the civilian convoy vehicles to a safe distance;
- do nothing and hope that the militia men let the unit and convoy through eventually;
- deploy the quick reaction force (QRF) and move artillery units to fire positions.

There are well-defined NATO rules of engagement:
- Personal and direct-fire weapons may be used to engage a positively identified threat;
- Indirect fire may be used to engage a positively identified threat.

Here the immediate potential outcomes of the mission are measured against attribute $\boldsymbol{x}_1$ and scored by utility function U_1. This evaluates features that have consequences local to the situation, such as an escalation of the immediate threat by ambush or weapon-firing, the reduced security of the civilians in the convoy and likelihood of kidnap, theft of supplies, etc. The second attribute $\boldsymbol{x}_2$ is scored by U_2, evaluating more global issues concerning, for example, the integrity of the NATO campaign and political perceptions of NATO's ability to show resolve while adhering to the rules of engagement. The nature of peace-support operations generally means that the C2 structure tends to be flatter and with

a less explicit hierarchy of mission orders (in contrast to the war-fighting scenario). Therefore we would expect the course of action selection to be driven more from the situation attributes than from the weighting of mission priorities.
The decision model then is as follows:
$\alpha_1(\lambda_1)$ is the subjective priority weighting of local effects.
$\alpha_2(\lambda_1)$ is the subjective priority weighting of global effects .
U_1 *(d,* $\beta_1(\lambda_1)$) is the utility of the decision with respect to local outcomes.
U_2 *(d,* $\beta_2(\lambda_1)$) is the utility of the decision with respect to more strategic consequences of the decision.
λ_2 is a vector of shaping parameters for the subjective distribution of probable outcomes, and represents the general level of the commander's uncertainty in the situation.

The local features for attribute $\boldsymbol{x}_1$ typically concern the potential for:
- Escalation of threat (in particular an ambush or firing of weapons);
- Loss of civilian life;
- Own force casualties;
- Theft of convoy assets;
- Taking of hostages.

Another $\boldsymbol{x}_1$ attribute, only explicitly mentioned by two participants, was time pressure in that there was only 40 minutes of daylight remaining.

The global features for attribute $\boldsymbol{x}_2$ are typically:
- Show of strength against NATO resolve to restore stability;
- Provocation to create over-reaction and heightened regional tension.

Table 2 shows the various utilities and attributes along with the choices of course of action. In order to plot (in two dimensions) the participants' decision space and situation assessments within the space in terms of $\boldsymbol{x}_1$, the features are combined into two measures that represent the seriousness of the terrorist threat and the sense of provocation through a show of strength. The former reflects the indications for ambush and imminent need to address a real threat with direct force. The latter measure embodies the features concerned with protection of the convoy and the need to avoid escalation.

Participants' course of action choices, *d*, can be set against a notional decision scale (reflecting the degree of overt force deployed) that ranges from "deploy the QRF with all available support (such as artillery and helicopters)" to "negotiate with IVCP troops and do NOT deploy QRF". Several participants chose to "find out more" by sending in reconnaissance assets. This supports the fundamental basis for the non-linear utility theory approach that there are two major control dynamics:
- the dynamics of the actual situation (in particular whether or not the situation is close to, or approaching, a critical condition that demands corrective action);
- the associated probability dynamic (situation uncertainty strongly inter-related with consequential utility and whose functional forms are captured by the λ parameters).

Figure 3 schematically represents the participants' situation assessments plotted in the two-dimensional space representative of $\boldsymbol{x}_1$. Each letter in Figure 3 corresponds to participant's assessment in the experiment. The position of the letter, and the associated arrow, indicate their stated position (abstracted to be in terms of the two-dimensional representation) of their situation assessment, and the arrows attempt to show how they

anticipate that the situation will develop. Overlaid onto this situation assessment plot is the grouping of the participants into their Course of Action choices. This representation goes some way towards an initial validation of the Rapid Planning process.

The courses of action are associated not only with the static assessment of the situation but also with the projection forward in time and the associated potential (and hence maybe feared) consequences. The subjective utilities are "folded" into the situation assessment to represent the question "Is there going to be a significant change that will demand corrective action?" evaluated in relation to what is at stake. The "significance" of the change is embodied in the subjective utility curves. So there is a utility score for each point in the decision space and, in general, for this example, the utility scores tend to become rapidly low towards the top right corner of the plot in Figure 3. The participants will have utility "slopes" of differing shape and steepness.

In addition to the assessment of the situation, there is an additional degree of confidence associated with the individual's training and previous experience. This confidence helps to manage uncertainty in the situation and allows the decision-maker to identify factors that help to discriminate between equally likely situation assessments. In Figure 3 we can see this through the differences in the actions taken by the [L,O,P] group of participants and the [G,C,R,T,X] group. The [L,O,P] group decide to negotiate and at the same time prepare (at first covertly) the QRF deployment so that if they detect an escalation of threat the QRF could be used either as a negotiation lever (now making the QRF deployment overt) or, if necessary, the QRF can be employed rapidly and decisively. The [G,C,R,T,X] group on the other hand, deal with situation uncertainty rather differently and decide to delay any decision to act until more information is made available.

The other groups express confidence in their assessments of the situation (and its consequential projection) and hence choose an appropriate CoA. Differences in CoA result from the weightings placed on the utility values associated with the consequencial situation attributes. For example, the [H,Q,M,D,V,I,K] group place a high weighting on the more global utility, U_2, associated with the broader NATO mission, that when balanced against U_1 (removing the IVCP and keeping the convoy moving) comes out in favour of negotiation with no QRF deployment.

Convoy Mission $\alpha_1(\boldsymbol{\lambda}_1)$	Strategic mission $\alpha_2(\boldsymbol{\lambda}_1)$	Convoy Utility $U_1(d,\beta_1(\lambda_1))$	Strategic Utility $U_2(d,\beta_2(\lambda_1))$	Situation Certainty $\boldsymbol{\lambda}_2$	Show and/or Provocation x_2	Serious Threat x_1	Course of Action Selected
High	Low	Reduce terrorist Strength		Certain		Ambush Theft Hostages	Deploy QRF

Low	High		Avoid escalation	Certain	Provocation		Negotiate & do NOT Deploy QRF
High	Low	Protect convoy	Unclear	Uncertain		Ambush	Recce & Report
High-Medium	Low-Medium	Potentially Serious Local threat	Alert for escalation indicators	Certain	Yes	Yes	Covertly deploy QRF & Negotiate
Medium	Medium	Not critical		Uncertain			Prepare & recce
High	Low	Not critical	Not critical	Certain			Prepare QRF and stand to
High	Low	Not critical	Not critical	Uncertain			Prepare & recce

Table 2: Utilities, attributes, and CoA for the peace-support scenario.

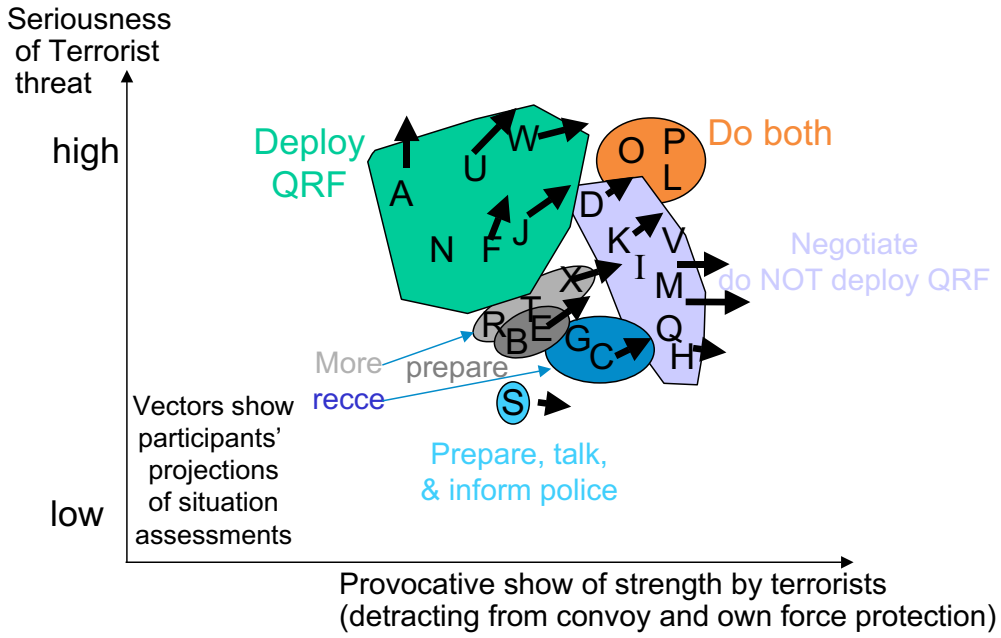

Figure 3: Participants' situation assessments and grouping of courses of action.

8. Non-linear Utility Theory and the Geometry of Competing Conflict Decisions

Let the shape parameters of the decision-maker's utility function, U, be denoted by λ_1. In practice, most Bayesian decision analyses usually begin by assuming that U has associated with it a set of m value independent attributes $\underline{x} = (x_1, x_2, \ldots x_m)$ [13]. This implies that a decision-maker's expected utility function has the form $U(d, \lambda_1, \lambda_2)$ and can be written as:

$$U(d, \lambda_1, \lambda_2) = \sum_{i=1}^{m} \alpha_i(\lambda_1) U_i(d, \beta_i(\lambda_1), \lambda_2)$$

where $0 \le \alpha_i(\lambda_1)$ for all i and $\sum_{i=1}^{m} \alpha_i(\lambda_1) = 1$, and λ_2 is the vector of shape parameters of his joint distributions or attributes.

The *criteria weights*, $\alpha_i(\boldsymbol{\lambda}_1)$ are chosen to reflect the importance of achieving the goal of the ith attribute, whose achievement is evaluated by the marginal utility $U_i(\theta_i \mid \beta_i(\lambda_1))$

Here the marginal utility $U_i(d, \beta_i(\lambda_1), \lambda_2)$ represents the expectation of $U_i(\theta_i \mid \beta_i(\lambda_1))$ for $1 \le i \le m$. The marginal utility $U_i(\theta_i \mid \beta_i(\lambda_1))$ is usually normalised so that, for all decision outputs $d \in D$

$$0 = \inf_{d, x_i} U_i(d, \beta_i(\lambda_1), \lambda_2) \le U_i(d, \beta_i(\lambda_1), \lambda_2) \le \sup_{d, x_i} U_i(d, \beta_i(\lambda_1), \lambda_2) = 1$$

and so , in particular, is a bounded function of its arguments.

The parameter vector $\boldsymbol{\beta}(\boldsymbol{\lambda}_1)=(\beta_1(\boldsymbol{\lambda}_1),\beta_2(\boldsymbol{\lambda}_1),\ldots,\beta_m(\boldsymbol{\lambda}_1))$ will parameterise the marginal utility functions, U_i, and determine their shape. Such parameters might determine the function's offset location, spread and turning points and specify how well the decisions, $d \in D$, achieve goals associated with attribute x_i. The decision-maker should then choose d to maximise $U(d, \lambda_1, \lambda_2)$ (averaging over the perceived outcomes and their utilities). The decision-maker has a free choice of how to set $\boldsymbol{\alpha}(\boldsymbol{\lambda}_1)$ and $\boldsymbol{\beta}(\boldsymbol{\lambda}_1)$, reflecting, for instance, his priorities and ambitions.

Formally, then, the commander's optimal decision is a course of action $d^* \in D$ that maximises his expected utility $U(d, \lambda_1, \lambda_2)$ where, for $1 \le i \le m$, we calculate the marginal expected utility by averaging over the possible outcomes θ_i relative to attribute x_i as follows;

$$U_i(d, \beta_i(\lambda_1), \lambda_2) = \int_{\theta_i} p_i(\theta_i \mid d, \lambda_2) U_i(\theta_i \mid \beta_i(\lambda_1)) d\theta_i$$

where $p_i(\theta_i \mid d, \lambda_2)$ is the perceived probability of outcome θ_i relative to goal attribute x_i, given decision d, and λ_2 is the shaping factor for this distribution. $U_i(\theta_i \mid \beta_i(\lambda_1))$ is the utility of outcome θ_i relative to goal attribute x_i, and $\beta_i(\lambda_1)$ is a shaping factor for this

utility function. The vector λ_2 will formally contain the hyper-parameters of his prior "belief" density and likelihood together with any data available to the commander at the time the course of action is chosen. (Of course, at best the commander will only approximate $p_i(\theta_i \mid d, \lambda_2)$).

In most military settings a decision-maker will be acting within a C2 structure and will be held accountable for his chosen course of action d. It is therefore reasonable to expect that the specific nature of the mission objectives and the previously absorbed general training will be reflected in the commander's choice of α and β.

At each level in the C2 structure, the mission statements, orders and rules of engagement must be interpreted by the commander and accommodated into his subjective utility attributes, with criteria weights which hopefully represent C2 priorities, at least approximately. We can simplify the missions described in this paper to just two levels of attributes, (i.e. m=2) but the general theory is not limited to two levels. As already indicated, the first attribute, x_1, measures the local outcome of the mission in terms of shorter-term, lower-order considerations (such as local own-force casualties). The second attribute, x_2, measures longer-term and more global concerns related to higher-order considerations, (for example, integrity of the NATO campaign).

Formally, the commander's decision is a course of action $d^* \in D$ that maximizes his expected utility $U(d, \lambda_1, \lambda_2)$. Hence by $d^*(\lambda)$ where $d^*(\lambda) = \sup_d |U(d, \lambda_1, \lambda_2)|$ (his *Bayes decision*).

In this paper it is sufficient to consider only examples where a mission's objectives can be described and formulated in terms of two attributes (i.e. m=2). In this case

$$U(d, \lambda_1, \lambda_2) = \alpha_1(\lambda_1)U_1(d, \beta_1(\lambda_1), \lambda_2) + \alpha_2(\lambda_1)U_2(d, \beta_2(\lambda_1), \lambda_2)$$

The parameter vector $\lambda=(\lambda_1,\lambda_2)$ contains shape parameters λ_2 of the commander's probability density over his attributes and parameters λ_1 of his marginal utility functions U_1 and U_2, (expressing his subjective assessment of the importance of deterioration of the situation in that particular component). The commander's task is equivalent to finding a $d^*(\lambda)$ such that $d^*(\lambda) = \sup |U(d, \lambda_1, \lambda_2)|$.

The space of decisions $d \in D$ will typically be very complex, and will be constrained by, for example, the available resources and the rules of engagement of the mission. However we contend that, at least to a good order of approximation, for a wide class of scenarios we will be able to express any course of action $d \in D = D_0 \times D_1 \times D_2$ in the form $d=(d_0, d_1, d_2)$ where $d_i \in D_i$, $0 \leq i \leq 2$ and where D_0 is a subset of the real line.

The first component d_0 of the decision d will describe those aspects of a course of action that have an effect both on the political success of the overall campaign and the immediate success of the current mission. Henceforth we implicitly assume that these aspects will oppose each other: a positive enhancement of the mission success being reflected in a negative effect on political implications and vice versa. A typical example might set d_0 to

measure the degree of force used in a particular course of action. Low values of d_0 will embody the complementary ideas of discretion and negotiation. This idea is summed up in the assumptions below.

The two marginal utilities U_1 and U_2 depend only on the arguments d_0,d_1 and d_0,d_2 respectively, so that $U_i(d,\beta_i(\lambda_1),\lambda_2)=U_i(d_0,d_i,\beta_i(\lambda_1),\lambda_2)$, where we assume that $d_0 \in D_0$ which is a subset of the real line.

Note that the co-ordinates d_1 and d_2 of the decision vector d index the precise way that the degree of force is employed and will typically be qualitative (although it could be sometimes quantified in terms of number of armoured units overtly deployed, for example). Usually d_1 will encode tactical-level effects and the choices will not affect U_2. It is common, at least in the UK, [17] for the precise nature of this level of the decision to be delegated to the tactical commander. The decision d_2 represents the higher-level operational effects more concerned with strategic goals, whose choice will not impact on the unfolding of the immediate situation as scored by U_1. Again, a large component of this may need to be made by the commander in the field in real time and in response to the developing situation.

For each tactical choice d_1, the function $U_1(d_0,d_1,\beta_1(\lambda_1),\lambda_2)$ is an assessment of the local mission outcome. The commander's training and experience will affect the choice of d through the components d_0 and d_1 tending to maximise $U_1(d_0,d_1,\beta_1(\lambda_1),\lambda_2)$. We note that the discontinuities in the decision process [7,10,12] focus on the geometry of this function and explain C2 hysteresis (leading to command paralysis).

Similarly, for each pair, d_0 ,d_2 , the function, $U_2(d_0,d_2,\beta_2(\lambda_1),\lambda_2)$ measures the commander's assessment of the consequences of d with respect to the longer-term and more global aims of the campaign (for example in terms of political impact of casualties and the integrity of the UN). Training and experience in politically sensitive combat scenarios, would refine the commander's judgements and should, for a given value of d_0, affect the tactical decision, d_2 such that $U_2(d_0,d_2,\beta_2(\lambda_1),\lambda_2)$ is as high as possible.

In this paper we focus on the issue of how a commander should balance his options and choose an appropriate value of d_0, given his own assessment of what he can achieve under these two objectives. To act rationally, a commander must, at least implicitly, evaluate the effectiveness of his most appropriate course of action d_i, for each of his goals, which, by definition, maximises $U_i(d_0,d_i,\beta_i(\lambda_1),\lambda_2)$ i=1,2, respectively. For each goal, this represents the tactic that maximises the effectiveness of his given mission combined with the best way of achieving this efficaciously . The problem then is how to balance these two potentially coflicting goals. He must then choose d_0 so as to maximise:

$$V(d_0|\boldsymbol{\lambda}) = \alpha_1{}^0(\boldsymbol{\lambda})V_1(d_0|\boldsymbol{\lambda}) + \alpha_2{}^0(\boldsymbol{\lambda})V_2(d_0|\boldsymbol{\lambda})$$

where for i=1,2,

$$V_i(d_0 \mid \lambda) = \frac{U_i(d_0,d_i,\beta_i(\lambda_1),\lambda_2)}{u_i(\lambda)}$$

$$u_i(\lambda) = \sup_{d_0 \in D_0} U_i(d_0,d_i,\beta_i(\lambda_1),\lambda_2)$$

$$\alpha_i^0(\boldsymbol{\lambda}) = \alpha_i(\boldsymbol{\lambda})u_i(\boldsymbol{\lambda}) / \alpha_1(\boldsymbol{\lambda})u_1(\boldsymbol{\lambda}) + \alpha_2(\boldsymbol{\lambda})u_2(\lambda_2)$$

Note that by this transformation, for i=1,2,

$$\inf_{do \in Do} V_i(d_0|\boldsymbol{\lambda}) = 0 \text{ and } \sup_{do \in Do} V_i(d_0|\boldsymbol{\lambda}) = 1$$

and $0 \le \alpha_i^0(\lambda)$ for i=1,2, with $\alpha_1^0(\boldsymbol{\lambda}) + \alpha_2^0(\boldsymbol{\lambda}) = 1$.

Note, however, that now $\alpha_i^0(\lambda)$ may depend on the parameters $\boldsymbol{\lambda}_2$ associated with the commander's uncertainty of outcome, as well as the shaping parameters $\boldsymbol{\lambda}_1$ of his utility function.
Through these mild assumptions we can represent a rational commander's choice of action as the value d_0 which he believes will balance the two conflicting goals most successfully (i.e. which maximises the real-valued $V(d_0|\boldsymbol{\lambda})$ given above). This function will typically be a mixture of a function V_1 in d_0 increasing (not necessarily strictly) from zero to one and another function V_2 in d_0 decreasing (not necessarily strictly) from one to zero, as shown in Figure 4. There has been considerable study of such mixtures (for example in [11]). As we have seen, it is possible to model in this way,under a few additional mild conditions, how a rational commander will qualitatively respond to various environments. These deductions compare well with the commander's CoA selection in single-decision experiments.

It is perhaps helpful to interpret what the two components and their weights represent in this study.

- The functions V_j (j =1,2) represents what the commander expects to score on his marginal utility $\boldsymbol{U}_j$ on attribute j by choosing CoA d_0 *relative* to the score he would expect to get if he chose d_0 to maximise his expected marginal utility U_j . Thus if he is very uncertain, then he will not be able to discriminate between the efficacy of broad ranges of d_0 , and so the function V_j will be flat. If on the other hand he can identify that certain options are significantly more promising for a component V_j then V_j will tend to be steeply changing on certain parts of the graph. Remember however that this is his own subjective assessment.
- The α_j^0 will take a low value if both the associated scored effectiveness U_j for any given d_0 is low and if the original importance α_j is also low. The α_j^0 will take a high value when both the associated scored effectiveness U_j for any given d_0 is relatively large (i.e. close to one) and if the original importance α_j is also high. Note that for U_j to be close to one usually requires that the commander is confident he can obtain close to the best possible outcome for the jth attribute (j =1,2). Of course, this confidence may be unfounded. Moderate values of these weights are obtained when the conditions (as described above) are mixed.

By describing the geometry of V and leaving the other, more context-specific, aspects of the maximisation implicit, we can focus on those aspects of the decision process that entail the balancing of the more globally compliant option against the more locally forceful option. Such aspects are the commander's experience (i.e. the assessment of his competence to choose appropriate tactics) and confidence in his ability to recognise the

need to revert to a forceful option should the situation demand. Figures 4,5 and 6 use the decision scale taken from the peace-support scenario to illustrate the geometry of V.

As we can see, in Figure 5, there is no conflict between the local and global goals and thus there is an area where compromise is possible. This is due to the fact that the level of force deployment to satisfy local goals is not in conflict with the force deployment to satisfy more global goals. As the difference between these increases, Figure 6 shows that there comes a point where these deployment levels are in conflict. In Figure 6, in order to maximise V, the decision-maker is split between two possible values of the decision d_0^* both giving maximum utility but where values in-between have relatively low utility. This implies a possible 'catastrophic' switch in decision by the commander. This process is brought together in Figure 7, which shows the discontinuous effect of a smooth increase in the separation of these local and global best force deployments, and the resultant switch.

In a separate paper [18] the mathematics of these 'bifurcation' effects is laid out in complete detail.

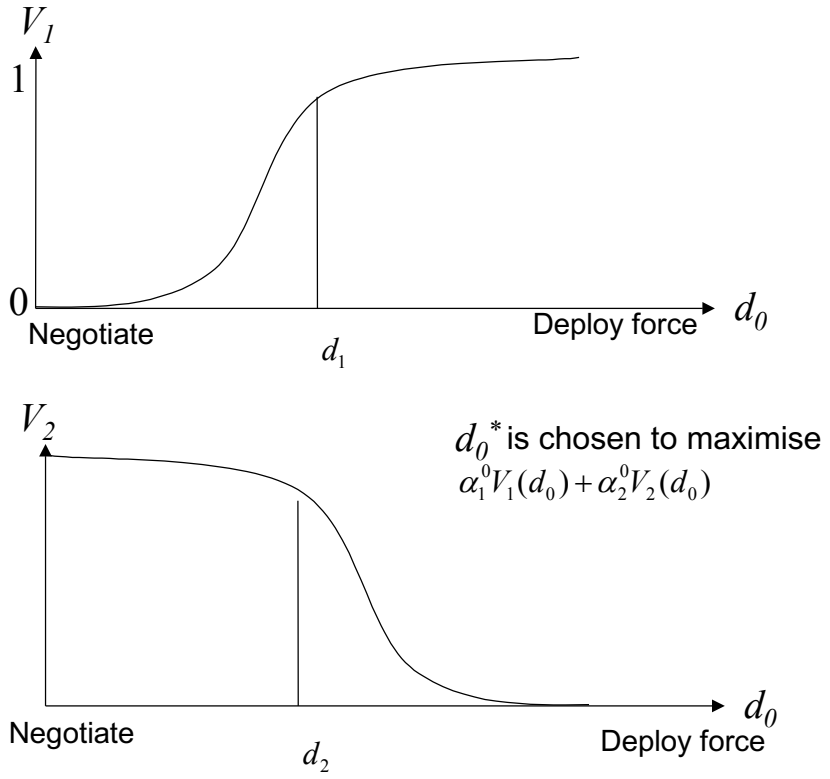

Figure 4: Utility values for two levels of command

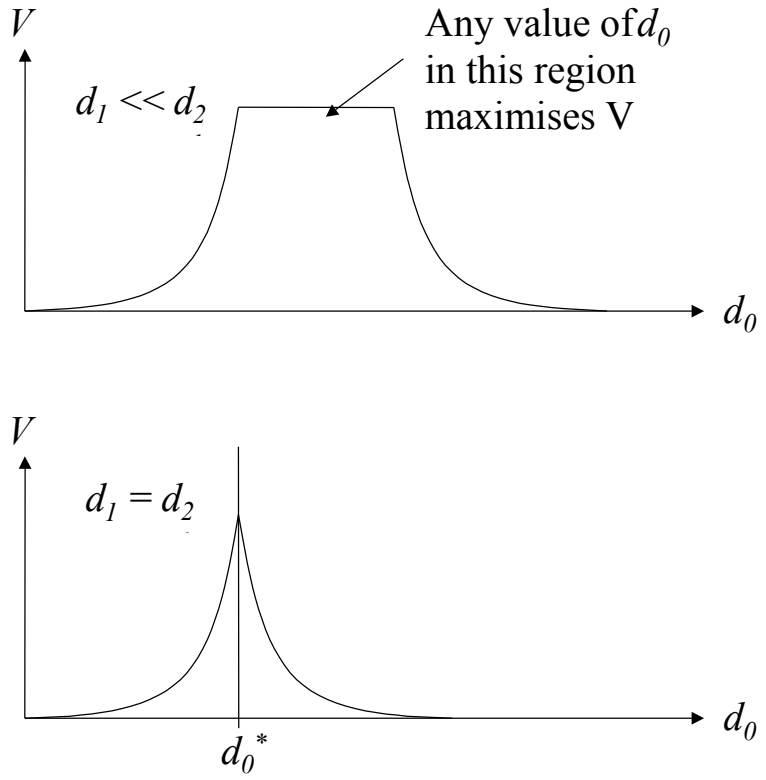

Figure 5: compromise solution where V1 and V2 coincide

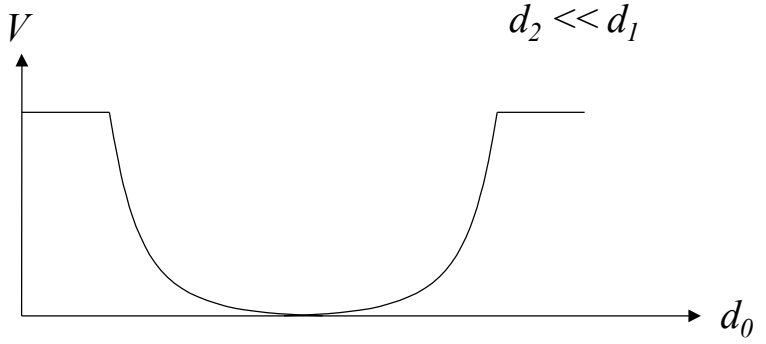

Figure 6: the split solution when the values of V_1 and V_2 are in conflict

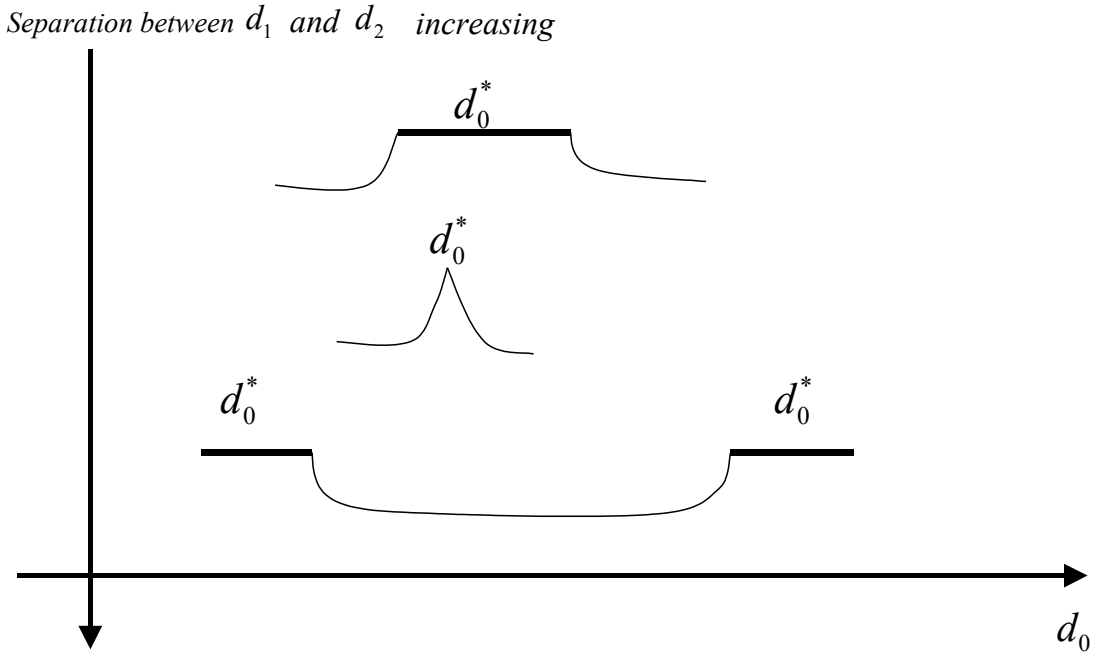

Figure 7: The effect of increasing separation of the locally best options.

9. Discussion and Conclusions

The Rapid Planning process, based on Bayesian Dynamic Linear Modelling, and the use of RPD-based pattern matching to determine a course of action, is the foundation for our current C2 modelling. The original extension of the DLM provided a means to incorporate discontinuities in decision outcome through subjective loss and belief functions set within a context of two (superior and subordinate) command levels. The initial modelling work showed that a minimisation of the decision-maker's expected loss results in two minima that relate directly to the mission objectives of the two command levels. The main criticism regarding the practicality of the initial model lay in the elicitation of a subjective loss function.

The experimental data has helped us to see that the subjective utility (or loss) function is essentially composed of two (or more) functions that represent assessment of the situation in terms of the decision-maker's local, short-term appreciation and a more global, longer-term appreciation of the potential consequences. When the two functions coincide, there is one solution (or even a range of decision options) that, given the decision-maker's set of situational attributes, appears to satisfy his own goal and that of his superior commander. When there is competition between the two goals, the decision-maker has to choose how to assign importance weights to each of the two goals. He could also choose to re-adjust his set of attributes in order to make his situation assessment consistent with this choice of weighting factors (some situation attributes may be totally disregarded.) The way in which a decision-maker has been trained will have a bearing on his choice of weighting factors (and attributes). His operational experience will give him confidence in his choice of weighting factors and will help him to appreciate what situational change would make it appropriate for him to re-adjust the weights. Personality and emotional history will also affect the choice of weighting factor but will tend to be more enduring and would emerge

probably as bias factors if we were able to gather enough data on the same individuals across many decision scenarios.

The results of the RPD experimental games show that differences in participants' uses of attributes to classify and assess (in terms of evaluated outcomes) where they are in their decision space (and in what direction they are going) result in differences in the selected courses of action. It is these subjective differences in the pattern-matching process that must be captured in future C2 models.

Non-linear utility theory offers a formal framework for defining the constraints, subjective utility functions and projection mechanisms for the determination of course of action, based on resolving the tension between local and more global considerations by the decision-maker. This analysis takes a first step in bringing together the naturalistic, subjective and human aspects of the RPD pattern-matching process and the quantitative aspects of non-linear utility theory. The analysis of the experimental data has extended the previous theory and draws together the Rapid-Planning process and Recognition-Primed Decision-making.

The aim of the non-linear utility analysis is to provide a quantitative formulation for explaining the decision responses in terms of the situation assessment attributes, their probability densities (including the situation projections) and the subjective utility functions. The inter-relationships between these elements make decomposition difficult but, if we are to inform lines of development investments regarding the balance between personnel selection, training and CIS decision support, it is essential that we are able to understand their contribution within the contexts of the operational drivers.

Consequently, this theory begins to explain the ways in which information, situation priors and pattern-matching, learnt comfort zones, fears and beliefs about the projected situation, training, local and global values all have an impact on decision outcome. It is still difficult to separate out the proportional impact that each one of these has on the decision process in terms of variability of outcome. It is also not yet possible to provide a parameterisation of the decision-maker, the situation and the consequential utility values so that these can be fed into the model to produce a predicted decision outcome. However, the model does provide a means of representing C2 decision-making for constructive simulations of military operations that will improve the current class of C2 agents. The theory also allows us to model hysteresis more naturally. It should improve understanding, and hence measurement of, the relative impact of command information, training and selection with the additional benefit of informing design of CIS to suit the staff, processes and organisational structures and the specific nature of the operational situation.

In summary, the approach can be used to develop a form of the Rapid Planning process which captures the subjective elements of command in closed form simulation models of conflict (where it is appropriate to do so). This will allow us to explore the emergent properties of interactions between C2 agents within different types of network structures where they are sharing not only situational information but also values and beliefs.

Acknowledgements

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Devolving command decisions in complex operations

L Dodd* and JQ Smith

Cranfield University, Defence Academy of the UK and University of Warwick, Wiltshire, UK

In contemporary military endeavours, Command and Control (C2) arrangements generally aim to ensure an appropriate regulation of command-decision autonomy such that decision makers are able to act in a way that is consistent with the overall set of commanders' intents and according to the nature of the unfolding situation. This can be a challenge, especially in situations with increasing degrees of uncertainty, ambiguity and complexity, also where individual commanders are faced with conflicting objectives. Increasingly, it seems that command decisions are being taken under conditions of internal command contention; for example, when the likely successful outcome of a tactical mission can often be at odds with the overall strategic and political aims of the campaign. The work in the paper builds on our previous research in decision making under uncertainty and conflicting objectives, where we analysed the responses of military commanders in decision experiments. We demonstrated how multi-attribute utility theory could be used to represent and understand the effects of uncertainty and conflicting objectives on a particular commander's choices. In this paper, we further develop and generalize the theory to show that the geometrical forms of expected utilities, which arise from the assumption of commander rationality, are qualitatively stable in a wide range of scenarios. This opens out into further analysis linking to Catastrophe Theory as it relates to C2 regulatory frameworks for devolving command decision freedoms. We demonstrate how an appreciation of this geometry can aid understanding of the relationship between socially complex operational environments and the prevailing C2, which can also inform selection and training of personnel, to address issues of devolving command decision-rights, as appropriate for the endeavour as a whole. The theory presented in the paper, therefore, provides a means to explore and gain insight into different approaches to regulation of C2 decision making aimed ultimately at achieving C2 agility, or at least at a conceptual language to allow its formal representation. C2 regulatory agents are discussed in terms of detailed functions for moderating command decision making, as appropriate for the degrees of uncertainty and goal contention being faced. The work also begins to address implications of any lack of experience and any differences in personality-type of the individual commanders with respect to risk-taking, open-mindedness and creativity.

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1. Introduction and background

The background for the theoretical work in this paper is an ongoing study of decision making under conditions of internal command contention and situational uncertainty, applied to the domain of military command and control (C2). The theory provides a foundation for the understanding of C2 agility. Therefore, the theory goes further than other military command decision studies, which treat C2 as a process (Wang and Wang, 2010) or model the commander as a player in a two-sided game (Medhurst *et al*, 2009). Nevertheless, the theory has been developed alongside a series of studies and has been supported, hence partially validated, by command decision-making experiments using UK Battle Group (BG) commanders (Dodd *et al*, 2003). The experiments presented BG commanders with situations of uncertainty and command contention, such that their courses of action, when seen from a tactical viewpoint, were potentially at odds with the broader campaign objectives. The experiments showed there were several ways in which the commanders dealt with the internal decision conflict:

- ignore the higher-level command objective completely;
- explicitly place little or no weight to the higher-level command objective;

*Correspondence: L Dodd, CfASS, DISE, Cranfield University, Defence Academy of the UK, Room MH101, Shrivenham, Wiltshire SN6 8LA, UK.

- explicitly place all or very great weight on the higher-level command objective at the expense of risking severe tactical losses;
- focus attention only on the attributes of the situation that give weight to the course of action that feels most comfortable;
- create a novel course of action that they hope might satisfy both objectives and might also 'hedge' against the uncertainty.

In Dodd *et al* (2006), we detail results from the BG command decision experiments studying how experienced personnel respond to conflicting objectives in two different scenarios. The first was a combat mission where there was high risk of casualties. The second was a peacekeeping mission with a risk of attack posed to a civilian convoy where the commander had to balance the efficacy of defence from attack and a negotiated passage. Participants formally documented their decision processes and their rationales for placing more or less weight and attention on objectives and situational attributes.

On the basis of these findings, the research challenge then was to develop the existing theory on discontinuity in decision making in order to further our understanding of how and when (and maybe then why) to adapt the weighting being placed on a given level of command objective. In other words, how might we understand how to apply a C2 regulatory function that acts as an arbiter agent, whose role is to balance the weightings and moderate command decision making according to the situation as a whole?

The particular concept around which the theory is set is drawn from UK defence doctrine, which introduced the concept of a C2 rheostat (MOD Joint Doctrine and Concepts Centre, 2003). As such, the C2 rheostat can be set to impose a top-down form of C2 at one extreme and a totally distributed form of C2 at the other extreme. Mission Command, generally adopted and used by the British military, lies at a mid-position and assumes that command intents are cascaded (usually downwards from strategic to operational to tactical) in a nested set of mission statements. For example, 'Search and clear area ALPHA and secure roads Y and Z in order to allow safe passage of civilians and humanitarian supplies in order to restore stability in the region'. Such orders are usually limited to stating only the intents of command levels that are two (and at most three) levels apart. It is for this reason that the theory developed here begins with an abstracted two-level problem, simplified to having two C2 agents, one whose role is to meet campaign objectives and the other whose role is to meet tactical objectives.

It follows then that the theory assumes there is a C2 regulatory 'arbiter' whose purpose is to determine the level to which decisions can be devolved (eg, decisions can be made without explicit reference back-up the command levels for authority to choose and carry out a tactical course of action). An extreme form of such devolved decision making has been simulated previously for the US Department of Defense (Alston *et al*, 2006) and was called an Edge Organization (Alberts and Hayes, 2003; because all forms of regulatory function and also all decision-rights were unilaterally devolved right down to the fighting elements at the edge). The key function of a C2 regulatory arbiter agent, therefore, is to determine the nature of the conditions (across the situation as a whole) under which decisions are being faced and then to moderate the devolution of decision making appropriately.

2. Introduction to the military problem

The premise for this paper is that military C2 decisions can be devolved to varying levels of decision maker, as appropriate for the prevailing operating conditions. For example, in the United Kingdom through Mission Command (Moffat, 2002), it has proved effective to communicate mission orders in broad terms only, and to devolve real-time tactical decision making to an experienced commander who is best placed and well able to appreciate and respond to what is happening on the ground.

This paper addresses the concept of a C2 regulatory agent whose purpose is to understand the implications of devolving decision making given the specific characteristics of the operational context and the conditions under which the decisions are being made. The C2 regulatory agent and the fielded commanders are therefore players in a collaborative game. The responsibility of the regulation of C2 decision making and the devolution of decisions usually resides within the role of a high level of command. (This is so, usually for good reason due to a real need for human judgement based on experience.) Such a C2 regulatory function is traditionally placed at a high level, and often remote position, of command. As such, only some aspects of the geometry of any particular commander's belief and utility functions are known. The work presented in this paper will make explicit what such a C2 regulatory function needs if it is to determine when to devolve decision making (ie, assuming that such discretionary trust can be granted to those who are in closest touch with ongoing events) and when to communicate orders more prescriptively (ie, adopting 'top-down' or centralized C2).

In this paper, building on our observations of the behaviour of experienced UK BG commanders in simulated decision scenarios (Dodd *et al*, 2006), we develop a more formal framework within which the degree of decision 'autonomy' can be related, via commanders' capabilities, to the specific demands of the operational context. We focus on those scenarios that are most difficult to manage: that is, those where there is goal contention

(ie, current tactical objectives conflict with broader campaign objectives) and situational uncertainty. This should help to form a basis for development of agents that can perform the C2 arbiter role and it will also provide a formal understanding of what is required to achieve C2 agility.

C2 decision regulation should generally aim to preserve coherence through *contiguity*; that is, encourage commanders of different battle groups within geographic or operational proximity to choose actions that are tactically and operationally coherent. For example, to try to avoid one commander retreating, while another is carrying out a hasty attack, with potentially chaotic and counter-productive consequences. C2 decision regulation should also strive to minimize command *contradiction*; that is, to avoid having to face a complete turnaround in a previously made decision. Maintenance of these two principles aims to avoid command decision stressors that can lead to, for example, hypervigilance (Janis and Mann, 1977) or decision suppression (Dodd, 1997), and can also jeopardize a commander's ability to subsequently act rationally and coherently. (Note that hypervigilance, which is a state of over-sensitivity to incoming sensory signals, and decision suppression are common in situations of high uncertainty and disorder.)

Furthermore, while small adjustments in intensity of engagement are often possible and can often be taken at limited cost, dramatic changes, where the commander faced with contradiction tries to dramatically adjust midstream, can be very costly in a wide range of scenarios.

UK military commanders, generally speaking, are expected to act rationally and accountably, within the context of their training and experience. Here, we interpret this expectation in a Bayesian way: commanders should choose a course of action that maximizes their expected utility (or at least tries to minimize their likelihood of loss). Explicitly, we assume that commanders choose a decisive action $\boldsymbol{d}\in\boldsymbol{D}$ from the potentially infinite set of decision options $\boldsymbol{D}$ available, so as to maximize the expectation of their utility function U. However, it would not be reasonable for a higher command to expect its personnel to try to evaluate and take into account the potential acts of all other contiguous commanders. Therefore, each commander will be treated as if they were an agent within a C2 regulatory framework.

The simplest way to capture the conflict scenario described above is to assume that each commander's utility function $U(\boldsymbol{d},\boldsymbol{x}|\boldsymbol{\lambda}_1)$ has two *value independent attributes* $\boldsymbol{x}=(x_1,x_2)$ (French and Rios Insua, 2000) with parameter vector $\boldsymbol{\lambda}_1$, which captures the overall shapes of the commanders' functions representing their beliefs and preferences related to outcomes. The first attribute measures the ongoing outcome-state of the current (tactical) mission. The second measures the extent to which the integrity of an overall campaign is preserved. The two sets of outcome measures may or may not have common elements; although variables such as number of casualties may be found in both sets of measures but then could be at differing levels of granularity. Under this assumption, for all decisions $\boldsymbol{d}\in\boldsymbol{D}$ and $x_i\in\chi_i$, where χ_i is the sample space of the attribute i ($i=1,2$) the commander's utility function has the form

$$U(\boldsymbol{d},x|\boldsymbol{\lambda}_1)=k_1(\boldsymbol{\lambda}_1)U_i(\boldsymbol{d},x_1|\boldsymbol{\lambda}_1)+k_2(\boldsymbol{\lambda}_1)U_2(\boldsymbol{d},x_2|\boldsymbol{\lambda}_1)$$

where each *marginal utility* $U_i(\boldsymbol{d},x_i|\boldsymbol{\lambda}_1)$ is a function of its arguments only and the *criteria weights* $k_i(\boldsymbol{\lambda}_1)$ satisfy $k_i(\boldsymbol{\lambda}_1)\geqslant 0$, $i=1,2$, $k_1(\boldsymbol{\lambda}_1)+k_1(\boldsymbol{\lambda}_1)=1$ (Keeney and Raiffa, 1976; von Winterfeldt and Edwards, 1986). The rational commander then chooses a decision option $\boldsymbol{d}^*(\boldsymbol{\lambda})\in\boldsymbol{D}$—called a *Bayes decision*—to maximize the expected utility

$$\bar{U}(\boldsymbol{d}|\boldsymbol{\lambda})=k_1(\lambda)\bar{U}_1(\boldsymbol{d}|\boldsymbol{\lambda})+k_2(\boldsymbol{\lambda})\bar{U}_2(\boldsymbol{d}|\boldsymbol{\lambda}) \qquad (1)$$

where $\boldsymbol{\lambda}=(\boldsymbol{\lambda}_1,\boldsymbol{\lambda}_2)\in\Lambda$—its possible set of values—and

$$\bar{U}_i(\boldsymbol{d}|\boldsymbol{\lambda})=\int U_i(\boldsymbol{d},x_i|\boldsymbol{\lambda}_1)p_i(x_i|\boldsymbol{\lambda}_2)dx_i \qquad (2)$$

The known vector $\boldsymbol{\lambda}_2$ will be a function of the hyperparameters defining the commander's subjective posterior distribution—here defined by $p_i(x_i|\boldsymbol{\lambda}_2)$ of attribute x_i, $i=1,2$.

We now investigate the extent to which a C2 regulatory agent can ensure that the commander's marginal utilities and criteria weights appropriately address the C2 regulatory *principles* of retaining contiguity and avoiding—as far as is possible—commander contradiction (and so maintaining overall coherence and balance).

The commander has a free choice of how to set (and adapt) the parameters $\boldsymbol{\lambda}_1$. However, the observed and appraised commander will have a utility function, which will reflect their understanding of the situation, their mission and campaign objectives. Qualitatively, a commander's courses of action can be classified into three broad categories, attempting to achieve simultaneously—at least partially—both the tactical objective and the broader campaign objectives. Henceforth, we will call this type of decision a *compromise*. On the other hand, in a scenario where no course of action is likely to attain satisfactory resolution of either the mission or campaign objectives simultaneously, a compromise will be perceived as futile. Rational choice will then need to focus on finding a *combative* action most likely to achieve the tactical mission objective while ignoring the broader campaign objectives or alternatively choosing a *circumspect* action—focusing on avoiding jeopardizing the campaign while potentially aborting the tactical mission. The transition from a rational act being a compromise between objectives to a stark choice between combat and circumspection can be explained through examining the geometry of a commander's expected utility function. This geometry is remarkably robust to the choice of parametric models that might be

being used to represent uncertainty and any belief in outcomes or intended consequences. The type of courses of action are determined according to:

1. qualitative features of the descriptors of the operational conditions (eg, turbulence Emery and Trist, 1965);
2. the uncertainty of the situation (eg, poor information, unfamiliar tactics);
3. the relative importance the commander places on the two objectives.

This robustness allows us to develop a useful general theory for decision making under conditions of internal command conflict and enables us to suggest remedial ways for a C2 regulatory agent to establish command conditions that will allow and encourage appropriate commander responses, taking commander capability into account. In the next section, we analyse how the geometry of the corresponding expected utility functions changes qualitatively under different combat scenarios and different types of commander. In Section 3, we demonstrate some general properties of rational decision making in this context. In Section 4, we discuss how, with some mild differentiability conditions, our taxonomy relates to the classification of catastrophes (Poston and Stewart, 1978; Zeeman, 1977) and give a number of illustrative examples. We end the paper by relating theory to observed behaviour and give some general recommendations for C2 regulation in the light of these geometrical insights.

3. Rational decisions for competing objectives

3.1 A probabilistic formulation

The commander's decision space $\boldsymbol{D}$ will consist of an open set of possible courses of action but will typically be constrained by many situational factors; for example, the available resources and the rules of engagement of the mission. However, for a wide class of scenarios we will be able to express any course of action $\boldsymbol{d}=(d,\boldsymbol{d}_1,\boldsymbol{d}_2)\in \boldsymbol{D}=D\times\boldsymbol{D}_1\times\boldsymbol{D}_2$ where D is a subset of the real line. In this paper, the component d will be a proxy measure for the *intensity* of the engagement associated with the chosen action. We assume that increasing the intensity of engagement does not reduce the commander's probability of successfully completing the tactical mission but is likely to have a potentially negative effect on the campaign (particularly now that military are involved mostly in stabilization operations). Thus, it is not unusual for a mission to be successfully addressed by engaging tactically with a large and sharp response. However, the intensity of the engagement increases the potential for casualties, both the commander's own unit and to the local civilian population. It is also likely to be increasingly politically deleterious and thus be increasingly to the detriment of the campaign objectives.

For a chosen level of engagement intensity d, a commander will choose, to the best of their ability, between other courses of action $\boldsymbol{d}_1(d)$ associated with satisfying the tactical mission objectives given d and between other courses of action $\boldsymbol{d}_2(d)$ associated with preserving the integrity of the campaign. Usually, $\boldsymbol{d}_1$ encodes specific tactics involved in achieving the current tactical mission. On the other hand, the decision $\boldsymbol{d}_2$ encodes the judgements involved in securing best use of human resources, preservation of life and retaining political integrity. Both $\boldsymbol{d}_1(d)$ and $\boldsymbol{d}_2(d)$ will usually be decided by the commander in the field and in response to the developing situation, although informed by protocol, rules of engagement and training. For the rest of this paper, we now assume that it is possible to define the engagement intensity d in such a way that these two subsequent choices do not impinge on one another. Formally, this will mean that a commander's expected marginal utility $\bar{U}_i(\boldsymbol{d}|\boldsymbol{\lambda})$ is a function only of $(d,\boldsymbol{d}_i,\boldsymbol{\lambda})$, $(d,\boldsymbol{d}_i)\in D\times\boldsymbol{D}_i$, $i=1,2$, where $D\subseteq\mathbb{R}$. $\boldsymbol{\lambda}$ is an index that represents the personal, institutional or conditional aspects, such as personal daring, preference, politics, etc.

Now let $\boldsymbol{d}_1^*(d)$, $(\boldsymbol{d}_2^*(d))$ denote, respectively, a choice with the 'best' likelihood of attaining the tactical mission objectives and campaign objectives (respectively) for a given intensity d. The assumption above makes it possible to characterize behaviour in terms of a one-dimensional decision space (see below). Figure 1 shows this dimension going from totally benign to super aggressive and also gives an illustration of a typical value plot.

Assuming that neither criterion weight is zero, in the Appendix we show that by taking a linear transformation

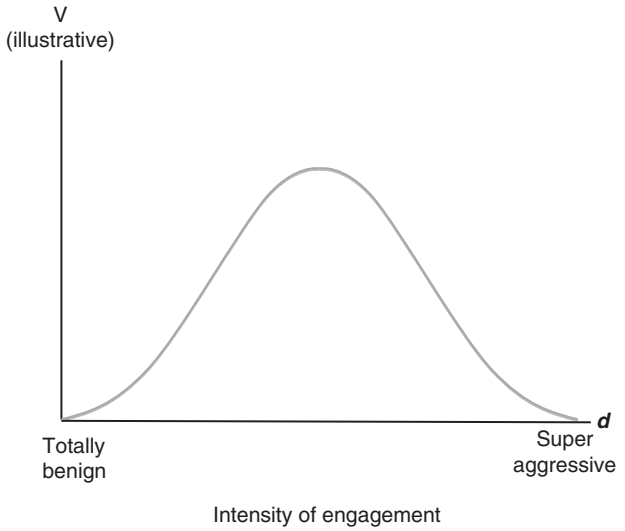

Figure 1 Illustrative shape of V values as a function of engagement intensity (d).

of the expression in Equation (1), a commander's Bayes decision d^* will maximize the function:

$$V(d|\boldsymbol{\lambda}) = e^{\rho(\boldsymbol{\lambda})} P_1(d|\boldsymbol{\lambda}) - P_2(d|\boldsymbol{\lambda}) \tag{3}$$

Here, temporarily suppressing the index $\boldsymbol{\lambda}$, for $i = 1, 2$

$$0 \leqslant P_1(d) = (u_1[1] - u_1[0])^{-1}(\bar{U}_1(d, \boldsymbol{d}_1^*(d)) - u_1[0]) \leqslant 1$$
$$0 \leqslant P_2(d) = (u_2[1] - u_2[0])^{-1}(\bar{U}_2(d, \boldsymbol{d}_2^*(d)) - u_2[0]) \leqslant 1$$

where the *daring* $\rho(\boldsymbol{\lambda})$ satisfies

$$\rho = \rho_1 + \rho_2 \tag{4}$$

where

$$\rho_1 = \log k_1 - \log k_2$$
$$\rho_2 = \log(u_1[1] - u_1[0]) - \log(u_2[1] - u_2[0])$$

and where for $i = 1, 2$, $u_i[0] = \inf_{d \in D} \bar{U}_i(d, \boldsymbol{d}_i^*(d))$ and $u_i[1] = \sup_{d \in D} \bar{U}_i(d, \boldsymbol{d}_i^*(d))$ denote the worst and best possible outcomes—as foreseeable in the eyes of the commander—for each of the objectives. For technical reasons, it will be convenient to reparametrize $\boldsymbol{\lambda}$ so that there is a one-to-one function from $\boldsymbol{\lambda}$ to $(\rho, \boldsymbol{\lambda}') \in \mathbb{R} \times \Lambda'$. Heuristically, $\boldsymbol{\lambda}'$ simply spans the parameters in Λ other than ρ. From the constructions above, it is clear that $P_1(d|\boldsymbol{\lambda})$, $P_2(d|\boldsymbol{\lambda})$ can be chosen so that they are only functions of $\boldsymbol{\lambda}$ through $\boldsymbol{\lambda}'$ and thus henceforth will be indexed as $P_1(d|\boldsymbol{\lambda}')$, $P_2(d|\boldsymbol{\lambda}')$.

Note here that $P_1(d|\boldsymbol{\lambda}')$ and $(P_2(d|\boldsymbol{\lambda}'))$ are, respectively, simply an increasing (decreasing) linear transformations of $\bar{U}_i(d, \boldsymbol{d}_i^*(d)|\boldsymbol{\lambda})$: the commander's expected marginal utility $i = 1, 2$ on making what is considered to be the best possible decision consistent with choosing an intensity d of engagement. From the definition of d, note that the functions $P_i(d|\boldsymbol{\lambda}')$ are each distribution functions in d: that is, non-decreasing in $d \in D$, with

$$P_i(\inf\{d \in D\}|\boldsymbol{\lambda}') = 0,\ P_i(\sup\{d \in D\}|\boldsymbol{\lambda}') = 1 \tag{5}$$

parametrized by $\boldsymbol{\lambda}' \in \Lambda'$, and $i = 1, 2$. Denote the smallest closed interval containing the support of $P_i(d|\boldsymbol{\lambda})$ by $[a_i(\boldsymbol{\lambda}'), b_i(\boldsymbol{\lambda}')]$, $i = 1, 2$ where by an abuse of notation we allow any of the lower bounds to take the value $-\infty$ and any of the upper bounds ∞. Thus, a_1 is the value below which the intensity d is deemed useless for attaining any even partial success in the mission. The upper bound b_1 is the lowest intensity that allows the commander to obtain total mission success. Similarly, a_2 is the highest value of intensity that can be used without damaging campaign objectives. The bound b_2 is the lowest value at which the campaign is maximally jeopardized. For obvious reasons, we will call $b_1(\boldsymbol{\lambda}')$ *pure combat* and $a_2(\boldsymbol{\lambda}')$ *pure circumspection*.

The meaning of these distributions can be best understood through the following simple but important special case.

Example 1 (zero—one marginal utilities) *When a mission is deemed to be either fully successful or to have failed so that the campaign is totally uncompromised or it is compromised, then $P_1(d|\boldsymbol{\lambda})$ is the commander's probability that the mission is successful using intensity d and choosing other decisions associated with the mission in the best way possible under this constraint. (See Figure 2 for an illustration.)*

On the other hand, $P_2(d|\boldsymbol{\lambda})$ is the probability that the campaign will be jeopardized if the commander used an intensity d. Note that the difference V defined above in Equation (3), balances these objectives, the relative weight given to mission success being determined by the value of the daring parameter ρ, with equal focus being given when $\rho = 0$.

In the more common scenarios where the mission can be partially successful, the interpretation of $Pi(d|\boldsymbol{\lambda})$, $i = 1, 2$ in fact relates simply to the special case above. Thus, specifically, the partially successful probable consequence of using and intensity d in the given scenario is considered by the commander to be *equivalent* to attaining best possible mission success with probability $P_1(d|\boldsymbol{\lambda})$ and the most jeopardization of the campaign with probability $P_2(d|\boldsymbol{\lambda})$.

One point of interest is that if $V(P_1, P_2, \rho, \boldsymbol{\lambda}')$ is given by Equation (3) and $Q_1 = P_2, Q_2 = P_1$ and $\tilde{\rho} = -\rho$, then $V(Q_1, Q_2, \tilde{\rho}, \boldsymbol{\lambda}')$ is a strictly decreasing linear transformation of $V(P_1, P_2, \rho, \boldsymbol{\lambda}')$. Therefore, in particular these two different settings share the same stationary points but with all local minima of $V(P_1, P_2, \rho, \boldsymbol{\lambda}')$ being local maxima of $V(Q_1, Q_2, \tilde{\rho}, \boldsymbol{\lambda}')$ and vice versa. Henceforth, call $V(Q_1, Q_2, \tilde{\rho}, \boldsymbol{\lambda}')$ the *dual* of $V(P_1, P_2, \rho, \boldsymbol{\lambda}')$. The close complementary relationship between the geometry of a problem and its dual will be exploited later in the paper.

3.2 Resolvability

Ideally, a C2 regulatory agent should be adaptive enough to alternate between devolving decision making to the commander in the field and taking a top-down approach

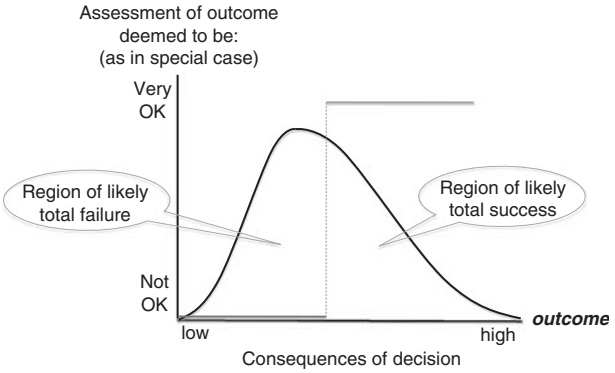

Figure 2 Composition of zero-one marginal utility function with an outcome probability function.

prescribing that each commander focus on carrying out actions to achieve one or other of the objectives. There are two scenarios where it is straightforward for a C2 regulatory agent to decide between full-scale devolution and a top-down C2 approach. The first occurs when $b_1(\lambda') \leqslant a_2(\lambda')$. Typically, in such conditions there is no overwhelming drive to be aggressive or purely combative. (See for illustration, Figure 3.)

We henceforth call this scenario *resolvable* for $\lambda' \in \Lambda'$ and call the closed interval $[b_1(\lambda'), a_2(\lambda')]$ the *resolution interval* for $\lambda' \in \Lambda'$. It is easy to see from Equation (3) that the set of the commander's optimal decisions require $d^*(\lambda') \in [b_1(\lambda'), a_2(\lambda')]$ when $V(d^*(\lambda')|\lambda') = \exp \rho(\lambda')$. Note that in particular both pure combat and pure circumspection are always Bayes decisions (as is any level of intensity between). In this case, although the commander's evaluation of performance $V(d^*(\boldsymbol{\lambda})|\boldsymbol{\lambda})$ is clearly dependent on ρ, their *decision* need not depend on ρ. Therefore, the choice is simply a moderate intensity of engagement $d^*(\lambda')$ in the interval above enabling the simultaneous recognition and acknowledgement of choices optimized on mission and campaign objectives from choosing $d_1^*(\lambda')$ and $d_2^*(\lambda')$ to maximize each of their respective marginal utilities. In fact, much military training focuses on this type of scenario, where there exists at least one course of action, which is 'OK' (Moffat, 2002) for both objectives. Good training regimes that ensure the commander can hedge (ie, identify both $(d^*(\boldsymbol{\lambda}), d_1^*(\boldsymbol{\lambda}))$ and $(d^*(\boldsymbol{\lambda}), d_1^*(\boldsymbol{\lambda}))$) will ensure that a utility maximizing strategy will be found and will not be influenced by the often unknowable parameter ρ. A C2 regulatory agent should be most prepared to devolve decision making to a commander on the ground when a situation is readily resolvable, as illustrated in thissimple case.

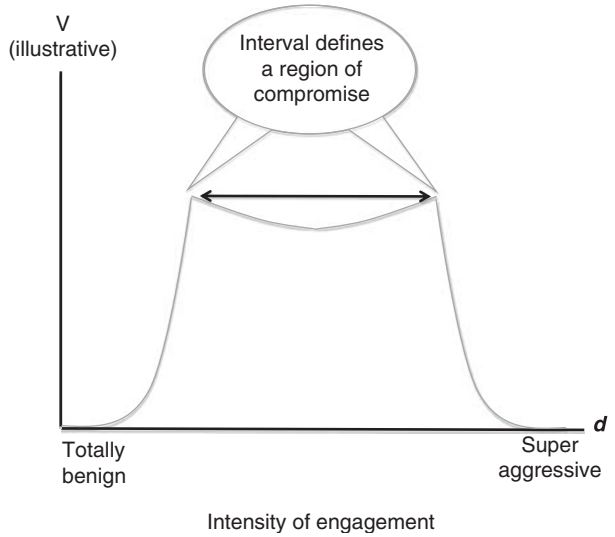

Figure 3 Illustrative shape of V against engagement intensity under conditions of resolvable contention, showing interval over d within which the decision conflict is potentially resolvable.

A second simple case occurs when $b_2(\lambda') \leqslant a_1(\lambda')$. Typically, in such conditions there is a high degree of contention when what is deemed to be OK for one is deemed to be absolutely not OK by the other. Henceforth, this scenario is called the *unresolvable* scenario for $\lambda' \in \Lambda'$. Here, there is no possibility of redeeming anything from one objective if the commander even partially achieves something towards the other. A rational commander's Bayes decision is either pure combat $d^*(\boldsymbol{\lambda}) = b_1(\lambda')$ optimizing mission objectives or pure circumspection $d^*(\boldsymbol{\lambda}) = a_2(\lambda')$ maximizing campaign objectives, choosing the first option if $\rho \geqslant 0$. In this scenario, a C2 regulatory agent therefore needs to account for the fact that a rational commander might apparently ignore completely one or other of the objectives depending on the sign of ρ. It is argued below that ρ can be unpredictable from the viewpoint of a C2 regulatory agent. Therefore, in such cases *which* of the two extreme reactions will be chosen will be difficult for a C2 regulatory agent to predict and control. C2 regulation should therefore be most inclined to be set as prescriptive in scenarios which are unresolvable and when $b_2(\lambda')$ and $a_1(\lambda')$ are far apart enough for the choice between them to cause discontiguity or contradiction.

When scenarios are such that both intervals $[a_i(\lambda'), b_i(\lambda')]$, $i = 1, 2$ are short—that is, when a commander will judge that the use of an intensity d will either result in complete failure or complete success except in a small range for both the mission or campaign objective—then most scenarios will be resolvable or unresolvable and appropriate C2 settings will usually be clear. Of course many scenarios have the property that by using a moderate level of intensity, compromise cannot be expected to fully achieve both objectives—as in the resolvable scenarios—but nevertheless might be a viable possibility—unlike in the unresolvable scenarios. The effect of an intensity d will have intermediate potential success with respect to the mission or campaign over a fairly wide range of values of d. To understand and control the movement from the resolvable to the unresolvable scenario, we will henceforth focus on these intermediate scenarios.

Call a scenario a *conflict* when $[a(\lambda'), b(\lambda')]$ is non-empty where $I(\lambda')$ is the open interval defined by

$$I(\boldsymbol{\lambda}') = (a_1(\boldsymbol{\lambda}'), b_1(\boldsymbol{\lambda}')) \cap (a_2(\boldsymbol{\lambda}'), b_2(\boldsymbol{\lambda}')) = (a(\boldsymbol{\lambda}'), b(\boldsymbol{\lambda}'))$$

Here, there is contention due to opposing viewpoints and different perspectives on the situation; conflict in the ways in which the situation might be expected to go in terms of outcomes and the differing assessments of success or loss given those outcomes, all of which are natural and tend to occur in contemporary operations typified by volatility, uncertainty, complexity and ambiguity.

The most important scenarios of this type are ones where one of the two intervals in the intersection above is not properly contained in the other. The first—the *primal* conflict scenarios—has $a(\lambda') = a_2(\lambda')$ and $b(\lambda') = b_1(\lambda')$. Here, the value of intensity at which the campaign begins to become progressively jeopardized is lower than the intensity at which the mission can be ensured to be fully successful.

Therefore, here we have a case in which there is a dominant priority for and preference towards the campaign aims taking precedence, yet the dominant views on the situation are from the more narrowly focused tactical mission perspective.

The second case—the *dual* conflict—has $a(\lambda') = a_1(\lambda')$ and $b(\lambda') = b_2(\lambda')$ is more difficult for the commander but has some hope because the intensity required to begin to have some success in the mission is lower than the intensity at which the campaign will be maximally jeopardized. Therefore, here we have a case in which there is a dominant priority for and preference towards the tactical mission aims taking precedence, yet the dominant views on the situation are from the broader focused campaign perspective.

Note that each of the primal scenarios with associated potential $V(P_1, P_2, \rho, \lambda')$ with bounds $[a_1, b_1]$ and $[a_2, b_2]$ on P_1, P_2, respectively, has a dual scenario associated with its dual $V(Q_1, Q_2, \tilde{\rho}, \lambda')$ whose bounds on are Q_1, Q_2 are, respectively, $[a_2, b_2]$ and $[a_1, b_1]$. It follows that the geometry of dual conflicts can be simply deduced from their corresponding primal conflicts. Say a scenario is a *boundary* conflict if $a_1 = a_2$ and $b_1 = b_2$.

Henceforth, assume that P_1 and P_2 are absolutely continuous with respective densities p_1 and p_2 and that p_1 and p_2 are strictly positive in the interior of their support and zero outside it. Then, it is straightforward to check from Equation (3) that when

$$\begin{aligned}
DV(d|\lambda) &= e^{\rho} p_1(d|\lambda') > 0 \text{ when } a_1(\lambda') < a_2(\lambda') \text{ and} \\
&\quad d \in (a_1(\lambda'), a_2(\lambda')) \\
DV(d|\lambda) &= -\, p_2(d|\lambda') > 0 \text{ when } a_1(\lambda') > a_2(\lambda') \text{ and} \\
&\quad d \in (a_1(\lambda'), a_2(\lambda')) \\
DV(d|\boldsymbol{\lambda}) &= -\, p_2(d|\lambda') < 0 \text{ when } b_1(\lambda') < b_2(\lambda') \text{ and} \\
&\quad d \in (b_1(\lambda'), b_2(\lambda')) \\
DV(d|\boldsymbol{\lambda}) &= e^{\rho} p_1(d|\lambda') > 0 \text{ when } b_1(\lambda') > b_2(\lambda') \text{ and} \\
&\quad d \in (b_1(\lambda'), b_2(\lambda'))
\end{aligned}$$

It therefore follows that whatever the value of $\lambda' \in \Lambda'$, we can find a Bayes decision $d^*(\lambda') \in I^+(\lambda')$ where

$$I^+(\lambda') = I(\lambda') \cup \{a_2(\lambda')\} \cup \{b_1(\lambda')\}$$

Henceforth, in this paper we will assume that the commander chooses their action from within the interval $I^+(\lambda')$. Therefore, in any of the above cases of decision conflict $d^*(\lambda') \in [a_2, b_1]$. In a dual scenario, $d^*(\lambda')$ is either at the extremes of intensity worth considering a_2 or b_1 or lies in the open interval (a_1, b_2). Therefore, the former is typical of some aspects of the ISAF campaign in Afghanistan, where there is a focus on stabilization and thus works against tactical missions focused solely on acting with great intensity.

The latter represents the warriors' preference for intense fighting set against their knowledge that they are there to establish and maintain stability and security.

We next study the effect of the value of the parameter ρ, which represents the degree of daring on a commander's decisions.

3.3 Daring and intensity of action

Fix the value of λ' and suppress this index. (This is representative of the regulatory agent being aware that it has only what it has in terms of the commanders' capacities for perceiving and understanding the situation, and this is fixed.) Then, for each $d > d', d, d' \in I^+(\lambda')$ with the property that $P_2(d) > 0$, there exists a large negative ρ such that

$$V(d|\boldsymbol{\lambda}) - V(d'|\boldsymbol{\lambda}) = e^{\rho}\{P_1(d) - P_1(d')\} - P_2(d') < 0$$

Thus, in this sense as $\rho \to -\infty$ the rational, accountable commander will choose a decision increasingly close to pure circumspection a_2. Such a condition may arise if there is great political pressure being brought to bear on the campaign and the eyes of the world's media are focused upon the decision makers.

On the other hand, for all fixed λ' for each $d < d', d, d' \in I^+(\lambda')$ with the property that $P_1(d) > 0$, there exists a large negative ρ such that

$$\begin{aligned}
e^{-\rho}(V(d|\boldsymbol{\lambda}) - V(d'|\boldsymbol{\lambda})) &= e^{-\rho}(P_2(d')) - P_1(d)) \\
&\quad - P_1(d) < 0
\end{aligned}$$

Therefore, as the daring parameter $\rho \to \infty$ becomes large and positive, the rational, accountable commander will choose a decision increasingly close to pure combat b_1. Such a condition may arise if there is great need for personal daring when a situation demands great courage, for example, to rescue an injured comrade in the heat of combat, irrespective of danger to the decision maker, the mission or the campaign.

Next, note that any rational commander will assess that if $d' < d$ and d' is not preferred to d when $\rho = \rho_0$, then d' is not preferred to d when $\rho = \rho_1$ when $\rho_1 \geqslant \rho_0$. To see this, simply note that

$$\begin{aligned}
V(d|\rho_1) - V(d'|\rho_1) &= (V(d|\rho_0) - V(d'|\rho_0)) \\
&\quad + (e^{\rho_1} - e^{\rho_0})(P_1(d) - P_1(d'))
\end{aligned}$$

The first term on the right-hand side is non-negative by hypothesis, while the second is positive since P_1 is a

distribution function. Further, by an analogous argument, if $d' > d^*$ and d' is not preferred to d^* when $\rho = \rho_0$, then d' is not preferred to d^*, when $\rho = \rho_1$, when $\rho_1 \leqslant \rho_0$ either. In this sense, a rational commander will choose to engage with non-decreasing intensity as ρ increases *whatever* the circumstances. We shall henceforth call this property *ρ-monotonicity*. Let

$$D^*(\rho, \boldsymbol{\lambda}') = \{d^*(\rho, \boldsymbol{\lambda}') : d^*(\rho, \boldsymbol{\lambda}') = \arg\sup\ V(d^*|\rho, \boldsymbol{\lambda}')\}$$

denote the set of optimal intensities $d^*(\rho, \boldsymbol{\lambda}')$ for a commander whose parameters are $(\rho, \boldsymbol{\lambda}')$. Note that ρ-monotonicity implies that if $D^*(\rho_0, \boldsymbol{\lambda}')$ contains pure circumspection, then so does $D^*(\rho, \boldsymbol{\lambda}')$ where $\rho < \rho_0$. Similarly, if $D^*(\rho_1, \boldsymbol{\lambda}')$ contains pure aggression, then so does $D^*(\rho, \boldsymbol{\lambda}')$ where $\rho > \rho_1$. When for some fixed value $\boldsymbol{\lambda}'$ and for ρ lying in the closed interval $[\rho_0, \rho_1]$, $D^*(\rho, \boldsymbol{\lambda}')$ consists of the single point $\{d^*(\rho, \boldsymbol{\lambda}')\}$. Then the monotonicity condition above and the strict positivity of $p_1(d^*|\boldsymbol{\lambda})$ or $\rho_2(d^*|\boldsymbol{\lambda})$ on their support then tells us this $d^*(\rho, \boldsymbol{\lambda}') \in I(\boldsymbol{\lambda}')$ is *strictly* increasing $\rho \in [\rho_0, \rho_1]$. So the larger the $\rho(\boldsymbol{\lambda}')$, the higher the priority placed on mission success. From the above, this will be reflected in the choice of intensity: the larger the value of $\rho(\boldsymbol{\lambda}')$, the greater the choice of intensity.

Recall from Equation (4) that the daring $\rho(\boldsymbol{\lambda}') = \rho_1(\boldsymbol{\lambda}') + \rho_2(\boldsymbol{\lambda}')$ decomposes into two terms. The term $\rho_1(\boldsymbol{\lambda}')$ is an increasing function of the relative weight placed on the mission against the campaign objectives; that is, their *prioritization*. Note also that it is the only term in V affected by a commander's criterion weights. This term may be potentially very unpredictable to a C2 regulatory agent, especially if no formal C2 education is practised or provided about how to balance mission and broader campaign objectives. Even with such C2 training or experience, the personality and emotional history will colour the commander's choice of this parameter.

The term $\rho_2(\boldsymbol{\lambda}')$ is an increasing function of how much better the commander believes they can achieve mission over campaign objectives were they able to choose an optimal intensity for either. This, of course depends on the scenario faced and their competence—something that a C2 regulatory agent might hope to estimate reasonably well. But, since it is based on their *own* evaluation of their competence it also reflects their relative *confidence* in their ability to achieve mission success or be sensitive to the campaign objectives. A commander's lack of training or difficult recent emotional history may well have a big affect on this term. Note that a large positive value of this parameter encourages the commander to focus almost entirely on the mission objectives, while a large negative value would encourage them to neglect the mission objectives in favour of the overall campaign objectives.

4. The developing bifurcation

4.1 Bifurcation with continuous potentials

Here, building on methodologies developed in Moffat (2002), Moffat and Witty (2002) and Smith *et al* (1981), we investigate the geometrical conditions determining when bifurcation of the expected utility can occur. When $V(d|\boldsymbol{\lambda})$ is continuous, a commander's optimal choice will move smoothly in response to smooth changes in $\boldsymbol{\lambda}$, provided that their best course of action $d^*(\boldsymbol{\lambda})$ is unique: see the Appendix for a formal statement of this property and a proof. Thus, the undesirable situations of there being dramatic differences between the Bayes decisions of contiguous commanders at $\boldsymbol{\lambda} = \boldsymbol{\lambda}_0 = (\rho_0, \boldsymbol{\lambda}_0')$ or a single commander suddenly faced with contradiction can only occur when $D^*(\rho_0, \boldsymbol{\lambda}_0')$ contains at least two Bayes decisions and hence in particular two local maxima. On the other hand, if $D^*(\rho_0, \boldsymbol{\lambda}_0')$ contains two decisions $d_1^*(\rho_0)$, $d_2^*(\rho_0)$ where $d_1^*(\rho_0) < d_2^*(\rho_0)$, then holding $\boldsymbol{\lambda}_0'$ fixed and increasing ρ through ρ_0 from the above we must jump from a $d^*(\rho) \leqslant d_1^*(\rho_0)$ being optimal $\rho \leqslant \rho_0$ to a $d^*(\rho) \geqslant d_2^*(\rho_0)$ being optimal. This in turn implies that a C2 regulatory agent can be faced with a lack of contiguity and commander contiguity whenever their daring is near ρ_0. Therefore, there is an intimate link between when it is expedient for a C2 regulatory agent to delegate and the cardinality of $D^*(\rho_0, \boldsymbol{\lambda}_0')$, which in turn is related to the number of local maxima of $V(d|\boldsymbol{\lambda})$.

Again suppressing the index $\boldsymbol{\lambda}'$, a rational commander will choose a non-extreme option $d^*(\boldsymbol{\lambda}) \in I(\boldsymbol{\lambda}')$ for some value $\rho(\boldsymbol{\lambda}')$ if and only if

$$V(d^*(\boldsymbol{\lambda})|\boldsymbol{\lambda}) = e^{\rho} P_1(d^*(\boldsymbol{\lambda})) - P_2(d^*(\boldsymbol{\lambda})) \geqslant \max\{e^{\rho} - 1, 0\}$$

that is,

$$P_1(d^*(\boldsymbol{\lambda}))\{P_2(d^*(\boldsymbol{\lambda}))\}^{-1} \geqslant e^{-\rho} \geqslant \{1 - P_1(d^*(\boldsymbol{\lambda})\} \times \{1 - P_2(d^*(\boldsymbol{\lambda})\}\}^{-1}$$

or equivalently

$$P_1(d^*(\boldsymbol{\lambda}))\{1 - P_1(d^*(\boldsymbol{\lambda}))\}^{-1} \geqslant P_2(d^*(\boldsymbol{\lambda})) \times \{1 - P_2(d^*(\boldsymbol{\lambda}))\}^{-1} \quad (6)$$

It follows, in particular, that if for all $d^*(\boldsymbol{\lambda}) \in I(\boldsymbol{\lambda}')$

$$P_1(d^*(\boldsymbol{\lambda})|\boldsymbol{\lambda}') \leqslant P_2(d^*(\boldsymbol{\lambda})|\boldsymbol{\lambda}') \quad (7)$$

that is, P_2 *stochastically dominates* P_1—then all commanders will have a Bayes decision either pure combat or pure circumspection, their choice depending on their daring, that is, act just as in an unresolvable scenario. Call such a scenario *pseudo-unresolvable*. Pseudo-unresolvable conflicts have the same difficult consequences as the unresolvable ones for C2 regulation and are therefore

strong candidates for prescriptive arrangements. Note that in our zero-one example above a scenario is pseudo-unresolvable if, for all $d \in I(\lambda')$, the probability of mission success using intensity d is no larger than the probability of jeopardizing the campaign.

When this domination is violated at some point $d_0 \in I(\lambda')$, then a C2 regulatory agent will predict that a commander with a particular level of daring will choose an interior decision, and thus compromise can be a viable option for at least some commanders. At the other extreme, when P_1 stochastically dominates P_2, then, for any commander, an interior decision $d^*(\lambda) \in I(\lambda')$ is at least as good as pure combat or circumspection. We now study the position and nature and development of these interior decisions under smoothly changing scenarios and personnel.

4.2 Bifurcation when distributions are twice differentiable

Henceforth, assume that the distributions P_i are twice differentiable in the open interval $(a_1(\lambda'), b_2(\lambda'))$, $i = 1, 2$ and constant nowhere in this interval. On differentiating and taking logs, any local maximum of $V(d|\lambda)$ will either lie on the boundary of I or satisfy

$$v(d|\lambda') \triangleq f_2(d|\lambda') - f_1(d|\lambda') = \rho \tag{8}$$

where $f_i(d|\lambda') = \log p_i(d|\lambda')$, $i = 1, 2$ where a necessary condition for this stationary point to be a local maximum of V is that the derivative $Dv(d|\lambda') \geqslant 0$. Therefore, in conflicting scenarios the commander's optimal decision $d^* \in I^+(\lambda')$ will either lie on the boundary of $I(\lambda')$—as in the unresolvable scenario—or satisfy the equation above.

Let $\xi_1(\lambda')$ ($\xi_1'(\lambda')$) and $\xi_2(\lambda')$ ($\xi_2'(\lambda')$), respectively, denote the mode of $p_1(d|\lambda')$ occurring at the largest (smallest) value of d (and hence the largest (smallest) maximum of $f_1(d|\lambda')$) in $(a_1(\lambda'), b_1(\lambda'))$ and the mode of $p_2(d(\lambda)|\lambda') = 0$ occurring at the smallest (largest) value of d (and hence the smallest (largest) maximum of $f_2(d|\lambda')$) in the open interval $(a_2(\lambda'), b_2(\lambda'))$. Note that when P_1 and P_2 are both unimodal $\xi_1(\lambda') = \xi_1'(\lambda')$, $i = 1, 2$. In this case, because $\xi_1(\lambda')$ is a point of highest incremental gain in mission, we call this point the *mission point* and the intensity $\xi_2(\lambda')$ where the threat to campaign objectives worsens fastest the *campaign point*.

When $\xi_1(\lambda') \leqslant \xi_2(\lambda')$, for any $d \in [\xi_1(\lambda'), \xi_2(\lambda')]$, $v(d|\lambda')$ is strictly decreasing. It follows that there is at most one solution d^* to Equation (8) for any value of ρ and $Dv(d|\lambda') \geqslant 0$ so this stationary value $d^* \in (a(\lambda'), b(\lambda')$ is a local maximum of V. Call a (primal) scenario *pseudo-resolvable* if

$$\xi_1(\lambda') \leqslant a_2(\lambda') \leqslant b_1(\lambda') \leqslant \xi_2(\lambda') \tag{9}$$

where a Bayes decision can only occur in the closed interval $[a_2(\lambda'), b_1(\lambda')]$. Clearly, in this case for each value of $\lambda \in \Lambda$ there is a unique maximum in this interval moving as a continuous function of λ.

It follows that a C2 regulatory agent should find pseudo-resolvable conflicts almost as desirable as resolvable ones and these are therefore prime candidates for devolved decision making. In particular, no rational commander will face the stark combative *versus* circumspection dichotomy. Furthermore, although their choice of act will depend on ρ, two commanders with similar utility weightings as reflected through their value of ρ will act similarly. Therefore, in particular it is rational for them to compromise and if contiguous commanders are matched by their training and emotional history, then they will make similar and hence broadly consistent choices. In the particular case when the distributions P_1 and P_2 are unimodal, pseudo-resolvable scenarios occur in primal conflict where the effectiveness of the mission of increasing intensity past $a_2(\lambda')$ is waning up to $b_1(\lambda')$, whereas the effect on mission compromise is accelerating. It therefore makes logical sense for a commander to compromise between these two objectives.

On the other hand, when $\xi_2'(\lambda') \leqslant \xi_1'(\lambda')$ for any $d \in [\xi_2'(\lambda'), \xi_1(\lambda')]$, $v(d|\lambda')$ is strictly increasing. It follows that there is at most one solution to Equation (8) for any value of ρ and $Dv(d|\lambda') \geqslant 0$ so this stationary value is a local minimum of V. It is easily checked that a (dual) scenario where

$$\xi_2'(\lambda') \leqslant a_1(\lambda') \leqslant b_2(\lambda') \leqslant \xi_1'(\lambda')$$

is pseudo-unresolvable and a Bayes decision can only be pure combat or pure circumspection.

4.3 Convexity and compromise

The next simplest case to consider is when $D^2v(d|\lambda')$ has the same sign for all $(a(\lambda'), b(\lambda'))$. This will occur, for example, when one of $f_2(d|\lambda'), f_1(d|\lambda')$ is convex and the other concave in $(a(\lambda'), b(\lambda'))$. In this case, clearly Equation (8) has no solution, two coincident solutions or two separated solutions in $(a(\lambda'), b(\lambda'))$. We have considered cases above when $v(d|\lambda')$ is increasing or decreasing in d, when one or no stationary point exists in the interval of interest. Below we focus on the case when there are two different solutions.

By our differentiability conditions, the two stationary points in $(a(\lambda'), b(\lambda'))$ a local maximum and a local minimum. Furthermore, it is easy to check that in a primal conflict when $D^2v(d|\lambda') > 0$, $d \in (a(\lambda'), b(\lambda'))$ and $p_1(a_1|\lambda') = 0$ the only maxima of V are either the smaller of these two intensities or $b_1(\lambda')$. On the other hand, when $D^2v(d|\lambda') > 0$ and $p_2(b_2|\lambda') = 0$, the only maxima of V are either $a_2(\lambda')$ or the larger of these two interior intensities. In these two cases, we have a choice between a compromise and an all-out attack—in the first scenario or total focus on the campaign in the second. In the dual case, we simply reverse the roles of maxima and minima in the above. Any

choice between the two options largely determined by ρ. Therefore, in all these cases C2 regulation avoids some possibilities of contradiction in the commander, but risks lack of contiguity.

It is often straightforward to find the solutions to Equation (8) when the two densities $p_1(d|\lambda)$, $p_2(d|\lambda)$ have a known algebraic form. We illustrate below a boundary scenario where $v(d|\lambda)$ satisfies the convexity conditions outlined above.

Example 2 (Zero-one utility/beta beliefs) *Consider the setting described in the example above where, for* $i=1,2$, $P_i(d|\lambda)$ *has a* β $B(\alpha_i,\beta_i)$ *density* $p_i(d|\alpha_i,\beta_i)$ *on the interval* $d\in[0,1]=I$ *(so* $a=0$ *and* $b=1$*) given by*

$$p_1(d|\alpha_1,\beta_1)=\frac{\Gamma(\alpha_1+\beta_1)}{\Gamma(\alpha_1)\Gamma(\beta_1)}d^{\beta_1-1}(1-d)^{\alpha_1-1}$$
$$p_2(d|\alpha_2,\beta_2)=\frac{\Gamma(\alpha_2+\beta_2)}{\Gamma(\alpha_2)\Gamma(\beta_2)}d^{\alpha_2-1}(1-d)^{\beta_2-1}$$

The function $V(d|\lambda)$ *is then differentiable in* d *for* $d\in(0,1)$*, and thus by Equation (8) the commander's decision will be (1)* $d=0$*—to keep intensity to the minimum and so minimally compromise the campaign (2)* $d=1$*—to engage with full intensity in order to attain the mission with highest probability or (3) to choose a compromise decision* d*, which satisfies*

$$\tau(d|\alpha,\beta)=\alpha\log d+\beta\log(1-d)=\rho' \qquad (10)$$

where $\alpha=\alpha_2-\beta_1$, $\beta=\beta_2-\alpha_1$ *and*

$$\rho'=\rho+\rho_3(\lambda')$$

where

$$\rho_3(\lambda')=-\log\frac{\Gamma(\alpha_1+\beta_1)\Gamma(\alpha_2)\Gamma(\beta_2)}{\Gamma(\alpha_2+\beta_2)\Gamma(\alpha_1)\Gamma(\beta_1)} \qquad (11)$$

Note in particular that in the two types of symmetric scenarios when $\alpha_1=\alpha_2$ *and* $\beta_1=\beta_2$ *or when* $\alpha_1=\beta_2$ *and* $\beta_1=\alpha_2$*, the term* $\rho_3(\lambda)=0$ *so that the parameter* ρ' *is exactly the daring* ρ*. Equation (10) implies that there are either* 0, 1 *or* 2 *interior critical points and* 0 *or* 1 *local maximum, which is a potential compromise solution, as well as the two extreme intensities. We consider* 4 *cases in turn*:

$\alpha>0$, $\beta<0$ *In this case,* $\tau(d|\alpha,\beta)$ *is strictly increasing on* $(0,1)$ *corresponds to a maximum of* V*. This compromise option is always better than fully committing to the mission or campaign objectives at the exclusion of the other.*

$\alpha<0$, $\beta>0$ *In this case,* $\tau(d|\alpha,\beta)$ *is strictly decreasing on* $(0,1)$ *corresponds to a minimum of* V*. In this situation, the rational commander will choose either* $d=1$*—purecombator,* $d=0$*—pure circumspection. The actual choice will depend on the value of* ρ'*—the larger* ρ' *the more inclined the commander is to choose combat.*

$\alpha>0$, $\beta>0$ *This occurs when, for example, the maximum negative effect on the campaign of a chosen level of intensity is approached much more quickly than the effect of intensity on the success of the mission. Here, it can be seen that* $\tau(d|\alpha,\beta)$ *has two values in* $(0,1)$*: the smaller a maximum and the larger a minimum of* V*. With large negative values of* ρ'*, the rational commander chooses a low but non-zero value of intensity obtaining almost optimal results associated with campaign objectives but allowing small chances of the mission success, which is more uncertain. As* ρ' *increases, for example, because the mission objectives are given a higher priority then this intensity smoothly increases. However, at some point before the intensity maximizing* τ *is reached the commander switches from the partial compromise to pure combat.*

$\alpha<0$, $\beta<0$ *This happens when, for example, the maximum negative effect on the campaign of a chosen level of intensity is approached much more slowly than the effect of intensity on the success of the mission. Here again* $\tau(d|\alpha,\beta)$ *has two values in* $(0,1)$*: but this time the smaller is a minimum and the larger a maximum of* V*. With large negative values of* ρ'*, the rational commander chooses pure circumspection, but as* ρ' *increases a point where the Bayes decision suddenly switches to a moderately high intensity this intensity smoothly increases to pure combat as* $\rho'\to\infty$*.*

All scenarios where $v(d|\lambda)$ is either strictly convex or concave exhibit an analogous geometry to the one discussed above: only the exact algebraic form of the equations governing the stationary point changes. Although surprisingly common in simple examples, this convexity condition is not a generic one. It cannot model all scenarios adequately, and competing decisions can often develop in subtler ways. In these cases, it is necessary to use somewhat more sophisticated mathematics to understand and classify the ensuing phenomena.

4.4 Conflict and differential conditions

For the purposes of this section, we make the qualitative assumption that for all values of $\lambda'\in\Lambda'$ $p_1(.|\lambda')$ and $p_2(.|\lambda')$ are both *unimodal* with its unique mission point mode denoted by $\xi_1(\lambda)$ and its unique campaign point mode

$\xi_2(\lambda')$. Further, assume that $p_1(.|\lambda')$ and $p_2(.|\lambda')$—are continuously differentiable on the open interval $(a(\lambda'), b(\lambda'))$. It will then follow that

$$\begin{aligned} &Df_1(d|\lambda') > 0 \text{ when } a(\lambda') \leqslant d < \xi_1(\lambda') \\ &Df_1(d|\lambda') < 0 \text{ when } \xi_1(\lambda') < d \leqslant b(\lambda') \\ &Df_2(d|\lambda') > 0 \text{ when } a(\lambda') \leqslant d < \xi_2(\lambda') \\ &Df_2(d|\lambda') < 0 \text{ when } \xi_2(\lambda') < d \leqslant b(\lambda) \end{aligned} \tag{12}$$

We have seen in the discussion of Equation (9) that when the mission point is smaller than the campaign point in a primal scenario, the Bayes decisions of all rational commanders are compromises and this decision is a continuous function of the hyperparameters and this is the only scenario, which is not bifurcated. We now study the complementary situation; thus, suppose for a $\lambda' \in \Lambda'$ the mode $\xi_2(\lambda') < \xi_1(\lambda')$: that is, the mission point is larger than the campaign point. Then, when $d \in (a(\boldsymbol{\lambda}), b(\boldsymbol{\lambda})) \cap (\xi_2(\lambda'), \xi_1(\lambda'))$

$$Dv(d|\boldsymbol{\lambda}) = Df_2(d|\boldsymbol{\lambda}') - Df_1(d|\boldsymbol{\lambda}') < 0 \tag{13}$$

this being true independently of the value of ρ. The stationary points $d_0(\boldsymbol{\lambda})$ of V satisfy Equation (8) so define a value ρ_0 such that

$$\begin{aligned} \rho_0(d_0(\boldsymbol{\lambda}), \boldsymbol{\lambda}') &= v(d_0(\boldsymbol{\lambda})|\boldsymbol{\lambda}') \\ &= f_2(d_0(\boldsymbol{\lambda})|\boldsymbol{\lambda}') - f_1(d_0(\boldsymbol{\lambda})|\boldsymbol{\lambda}') \end{aligned} \tag{14}$$

This implies that any choice of ρ_0 making $d_0(\rho_0, \boldsymbol{\lambda})$ a stationary point makes $d_0(\boldsymbol{\lambda})$ a local minimum of $V(\mathrm{d}|(\rho_0, \lambda'))$ and furthermore this is unique. It follows by Equation (9) that in a primal scenario $V(d_0|\boldsymbol{\lambda})$ must have one local maximum $\varsigma_2(\boldsymbol{\lambda}) < \xi_2(\boldsymbol{\lambda})$, and a local maximum $\varsigma_1(\boldsymbol{\lambda}) > \xi_1(\boldsymbol{\lambda})$. The scenario is therefore bifurcated and will present possible problems for C2 regulation.

Since $Dv(d|\boldsymbol{\lambda}) < 0$ for *any* value of ρ for any $d \in (a(\boldsymbol{\lambda}), b(\boldsymbol{\lambda})) \cap \xi_2(\boldsymbol{\lambda}), \xi_1(\boldsymbol{\lambda})$ then in particular no Bayes decision can lie in this interval a phenomenon described by Zeeman (1977) as *inaccessibility*. In particular fixing λ' and running ρ from $-\infty$ to ∞. From the monotonicity property $d_0^*(\rho)$ is discontinuous in ρ at some value $\rho^*(\lambda')$: $\rho_1(\lambda') < \rho^*(\lambda') < \rho_2(\lambda')$. The set of optimal decisions thus bifurcates into two disjoint sets: either lying in the interval $[a(\lambda'), \varsigma_2(\lambda')]$ and be of 'low intensity' more consistent with campaign objectives or be in $[\varsigma_1(\lambda'), b(\lambda')]$ and be of 'high intensity' and be more consistent with mission objectives.

Thus, when $\xi_2(\lambda') < \xi_1(\lambda')$ C2 regulation cannot avoid a potential lack of contiguity, even in primal scenarios. Furthermore, the smaller the campaign point $\xi_2(\lambda')$ relative to the mission point $\xi_1(\lambda')$, the larger the inaccessibility regions will tend to be and so the worse the potential lack of contiguity. Thus, the relative position of the mission and campaign points has a critical role in the geometrical description of the resolvability of conflict for the rational commander.

5. Links to catastrophes

5.1 Catastrophes and rational choice

The bifurcation phenomenon we have described in this paper is actually a more general example of some well-studied singularities, especially the cusp (and dual cusp) catastrophe, which are classified for in infinitely differentiable functions (see, eg, Poston and Stewart, 1978; Zeeman, 1977; Harrison and Smith, 1980). Thus, for the purposes of this section assume now within the interval $d \in (a(\boldsymbol{\lambda}), b(\boldsymbol{\lambda}))$ that $V(d|\boldsymbol{\lambda})$ is infinitely differentiable in d and consider the points $(d^0, \boldsymbol{\lambda}_0) \in I \times \Lambda$ of $(d, \boldsymbol{\lambda})$, which are stationary points in this interval: that is, that satisfy Equation (8). On this manifold the points for which the next two derivatives of this function are zero: that is, the parameter values $\lambda' \in \Lambda'$ of the two densities and a stationary value of d

$$Df_1(d^0|\boldsymbol{\lambda}_0') = Df_2(d^0|\boldsymbol{\lambda}_0') \tag{15}$$

are called *fold points*. If in addition we have that at that stationary value

$$D^2 f_1(d^0|\boldsymbol{\lambda}_0') = D^2 f_2(d^c|\boldsymbol{\lambda}_0') \tag{16}$$

also holds then such $\lambda \in \Lambda$ is called a *cusp point*. These points are of special interest, because near such values $\lambda_0 \in \Lambda$ the geometry of $V(d|\boldsymbol{\lambda})$ changes. In the zero, one example these points will be largely determined by the *actual* situation faced by the commander.

An important theorem called the Classification Theorem demonstrates that for most functions V and dimensions of the non-local and scale parameters in $\boldsymbol{\Lambda}$ less than 7; the way this geometry changes can be classified into a small number of shapes called catastrophes (Zeeman, 1977), each linked to the geometry of a low-order polynomial. In our case, the cusp points and fold points are especially illuminating because we will see below that, in many scenarios, the commander's expected utility will exhibit a geometry associated with one of the two of these catastrophes: the cusp catastrophe in the case of primal scenarios and the dual cusp catastrophe in the dual scenario.

Suppose that Λ can be projected down on to a two-dimensional subspace $C \subseteq R^2$, $C \subseteq \Lambda$, called the *control space*. Suppose this contains a single cusp. The cusp is a continuous curve in C with a single point $c(\boldsymbol{\lambda}_0')$ called the *cusp point*, where the curve is not differentiable and turns back on itself to form a curly v shape. Points on this continuous line are called *fold points*. Their coordinates can be obtained by solving the first two equations above in $\boldsymbol{\lambda}$ and then projecting these on to C.

It is convenient to parametrise the space C using coordinates (n, s), which are oriented around this cusp.

The *splitting factor s* takes a value 0 at the cusp point along the (local) line of symmetry of the cusp orientated so that positive values lie within the *v*. We will see below that typically in this application, in symmetric scenarios the splitting factor is increasing of the distance $\xi_2(\lambda')-\xi_1(\lambda')$ between the campaign and mission points of the commander's expected utility. This is, however, not a function of ρ, and thus in particular is not a function of the weighted utilities. In this sense, it is somewhat a feature of the scenario faced by the commander, rather than the commander *per se*, and thus, in particular, is a more robust feature for a C2 regulatory agent to estimate. The *normal factor n* also takes a value 0 at the cusp point and is orthogonal to *s*. In our examples, it is always a function of the parameter ρ, as well as other features that might make the problem non-symmetric and can in principle take any value depending on the commander's criterion weights.

It has now been shown that under a variety of regularity conditions, discrete mixtures of two unimodal distribution typically exhibit at most on cusp point (see eg, Smith, 1979, 1983). When $V(d|\boldsymbol{\lambda})$ exhibits a single cusp point, its geometry is simple to define. For values of $\boldsymbol{\lambda}\in\boldsymbol{\Lambda}$ such that $(n(\boldsymbol{\lambda}), s(\boldsymbol{\lambda}))$ lies outside the *v* of the cusp. There is exactly one stationary point d^* of $V(d|\boldsymbol{\lambda})$ where *d* is in the open interval (a, b); under the assumptions above d^* must be a local (and therefore global) maximum of $V(d|\boldsymbol{\lambda})$, and thus the commander's best rational choice. In this scenario, because $d^*\in(a, b)$ this course of action can be labelled as a compromise between the two objectives. The extent to which the compromise will favour one of the two objectives will depend of the commander's current values of $\boldsymbol{\lambda}\in\Lambda$, which in turn depend on his prioritization and beliefs. In this region, $d^*(\boldsymbol{\lambda})$ will be continuous in $\boldsymbol{\lambda}$ and thus evolve continuously as the commander's circumstances evolve.

On the other hand, for values of $\boldsymbol{\lambda}\in\Lambda$ such that $(n(\boldsymbol{\lambda}), s(\boldsymbol{\lambda}))$ lies within the *v* of the cusp, under the assumptions above there will (exceptionally) be two turning points and a maximum, or (typically) two maxima, $d^*(1)$ and $d^*(2)$ and a minimum. In the latter usual scenario, the commander's optimal choice will depend on the relative height of these local maxima. If the maximum $d^*(1)$ closer to *a* is such that $V(d^*(1)|\boldsymbol{\lambda})>V(d^*(2)|\boldsymbol{\lambda})$ where $d^*(2)$ is the maximum closer to *b*, then the rational commander chooses a low intensity option. If $V(d^*(1)|\boldsymbol{\lambda})>V(d^*(2)|\boldsymbol{\lambda})$, then the rational choice is the higher intensity option. Note that this is analogous to the circumstances we have described above. In this case, C2 regulation can experience lack of contiguity and regret at least for central values of ρ.

The dual scenario, which is less favourable, has an identical geometry but with maxima and minima permuted. Since rational behaviour is governed by maxima, the behavioural consequences on the commander of the geometry are quite different. Outside the *v* of the cusp, optimal decisions are thrown on to the boundary and the scenario becomes pseudo-unresolvable. On the other hand, parameters inside the *v* of the cusp allow there to be an interior maximum of the expected utility, as well as the two extreme options. Usually, as we move further into the *v* of the cusp, the relative efficacy of the interior decision improves relative to the extremes until the Bayes decision becomes a compromise decision.

Rather than dwell on these generalizations, we now move on to demonstrate the geometries explicitly for some well-known families of distribution.

5.2 Some illustrative examples

Example 3 (Zero—one β catastrophe) *From the catastrophe point of view, this is particularly simple. The fold points are obtained as solutions of* $D\tau=0$, *which lie in the interior* $(0,1)$ *of the space of possible Bayes decisions. The solution in terms of* $d^*=\alpha(\alpha+\beta)^{-1}$ *lies in* $(0,1)$, *if and only if* α *and* β *are of the same sign: the last two of the four special cases we analysed. Explicitly they are given by* $\alpha\beta>0$ *and*

$$(\rho', \alpha, \beta) = (\rho^{f\prime}(\alpha, \beta), \alpha, \beta)$$

where

$$\rho^f(\alpha, \beta) = \alpha\log\alpha + \beta\log\beta - (\alpha+\beta)\log(\alpha+\beta)$$

It is easy to check there are no cusp points satisfying the above. Here, the control space can be expressed in one dimension, and this one-dimensional space summarizes the geometry of the their commander's utility function, as described earlier. Once a C2 regulatory agent identifies whether the scenario is primal or dual and whether $\alpha\beta<0$ *or* $\alpha\beta>0$ *the value of* $\rho^f(\alpha,\beta)$ *and whether or not the value of* $\rho'<\rho^f(\alpha,\beta)$, *if* $\rho^f(\alpha,\beta)$ *exists explains the range of possibilities. In this sense, the existence and position of fold points is intrinsic to understanding the geometry. Finally, note that this geometry is qualitatively stable in the sense that other utilities satisfying the same strict convexity/concavity condition illustrated in this example can never exhibit cusps and will exhibit exactly analogous geometry of projection of its singularities but be governed by different equations on different hyperparameters.*

Because this is a boundary scenario, the above example is not general enough to capture all important geometries that C2 may encounter. Typically, these cases include cusps. Consider the following example.

Example 4 (gamma distributions) *Suppose the distributions* P_1 *and* P_2 *are (translated) gamma distributions having log densities on* $(a=0,\ b=2\bar{b})$ *given by*

$$f_1(d) = c_1 + \beta_1 m_1\log(2\bar{b}-d) - \beta_1(2\bar{b}-d)),\ d\leqslant 2\bar{b}$$
$$f_2(d) = c_2 + \beta_2 m_2\log d - \beta_2 d,\ d\geqslant 0$$

where $c_i = \alpha_i \log \beta_i - \log \Gamma(\alpha_i)$, $m_i = \beta_i^{-1}(\alpha_i - 1)$ *and* $\alpha_i, \beta_i > 1$ *so that each density has its mode strictly within the interior of its support. The Equation (3) of the stationary points of the commander's expected utility is then*

$$\beta_2 m_2 \log d - \beta_2 d - \beta_1 m_1 \log(2\bar{b} - d) + \beta_1(2\bar{b} - d) = (\beta_1 + \beta_2)\rho'$$

where $\rho' = (\beta_1 + \beta_2)^{-1}(\rho + c_1 - c_2)$ *Letting* $\beta = \beta_1(\beta_1 + \beta_2)^{-1}$, $\delta = d - \bar{b}$ *this simplifies to*

$$(1-\beta)m_2 \log(\bar{b} + \delta) - \beta m_1 \log(\bar{b} - \delta) - \delta = \rho' + (1 - 2\beta)\bar{b}$$

The modes of the two densities on δ *are given by the mission point* $\xi_1 = \bar{b} - m_1$ *and campaign point* $\xi_2 = m_2 - \bar{b}$. *By differentiating with respect to* δ *substituting and reorganizing it follows that the fold points for* δ *such that* $-\bar{b} < \delta < \bar{b}$ *must satisfy the quadratic equation*

$$\delta^2 + [(1 - 2\beta)\bar{b} - (\beta\xi_1 + (1 - \beta)\xi_2)]\delta + \bar{b}(1 - \beta)\xi_2 - \beta\xi_1) = 0$$

This scenario can therefore be identified with the canonical cusp catastrophe (Zeeman, 1977), whose fold points are also given by a quadratic. In particular its cusp points satisfy

$$\delta = [(1 - 2\beta)\bar{b} - (\beta\xi_1 + (1 - \beta)\xi_2)]$$

The fold points exist when

$$[(1 - 2\beta)\bar{b} - (\beta\xi_1 + (1 - \beta)\xi_2)]^2 \geqslant 4\bar{b}((1 - \beta)\xi_2 - \beta\xi_1)$$

Note that when $\alpha_1 = \alpha_2 = \alpha$ *and* $\beta_1 = \beta_2 = \beta'$ *so that* $\beta = 1/2$ *and* $\xi_1 = -\xi_2$ *this simplifies to there being fold points only when* $\xi_2 \leqslant \xi_1$ *and a cusp point at* $(\delta, \xi_1, \xi_2) = (0, 0, 0)$. *This is consistent with the results concerning inaccessibility discussed after Equation (12) and the two competing decisions get further apart as* ξ_1 *and* $\bar{b}$ *increase since the fold points are given by* $\delta = \pm\sqrt{\bar{b}\xi_1}$ *with inaccessible decisions between these two values.*

Example 5 (dual gamma) *In the dual scenario to the one described above, the cusp point defines the emergence of a compromise solution whilst pure circumspection* $a = 0$ *and pure combat* $b = 2\bar{b}$ *are always competing local maxima of the expected utility. However, as the modes* ξ_1 *of* Q_2 *and* ξ_2 *of* Q_1 *become increasingly separated, the compromise region grows and becomes the Bayes decision of most commanders.*

Although being able to identify this phenomenon with a canonical cusp/dual cusp catastrophe as above is unusual, for many pairs of candidate distribution the most complicated singularity we encounter is usually a cusp catastrophe. Thus, consider the following example.

Example 6 (Weibull distributions) *Let* X *have an exponential distribution with distribution function* $1 - \exp - 1/2x$ *and suppose that the distribution functions* P_1 *and* P_2 *are the distributions of* $X_1 = 2(\sigma^{-1}\{b - X\})^c$ *and* $X_2 = 2(\sigma^{-1}\{X + a\})^c$ *so that for* $d \in (a(\boldsymbol{\lambda}), b(\boldsymbol{\lambda}))$, $a(\boldsymbol{\lambda}) < b(\boldsymbol{\lambda})$ *the respective densities on this interval are given by*

$$p_1(d) = e^r(b - d)^{c-1} \exp\left\{-\tfrac{1}{2}\left\{\sigma^{-1}(b - d)\right\}^c\right\}$$
$$p_2(d) = e^r(d + a)^{c-1} \exp\left\{-\tfrac{1}{2}\left\{\sigma^{-1}(d + a)\right\}^c\right\}$$

Here $\sigma > 0$ *and for simplicity we will assume* $0 < c \leqslant 2$. *Note that when* $c > 1$, *the densities are unimodal with mission point* $\xi_1(\boldsymbol{\lambda}) = b - \sigma\{2(1 - c^{-1})\}^{1/c}$ *and campaign point* $\xi_2(\boldsymbol{\lambda}) = a + \sigma\{2(1 - c^{-1})\}^{1/c}$ *and stationary points satisfy*

$$f_2(\delta) - f_1(\delta) = (c - 1)[\log(\delta + \bar{b}) - \log(\bar{b} - \delta)] - \tfrac{1}{2}\sigma^{-c}\left[(\delta + \bar{b})^c - (\bar{b} - \delta)^c\right] = \rho \qquad (17)$$

where $\bar{b} = 1/2(b - a)$ *and* $\delta = d - 1/2(a + b)$*—so that* $-\bar{b} \leqslant \delta \leqslant \bar{b}$. *Differentiating and rearranging this expression when* $c \neq 1$ *decisions on the fold points must also satisfy*

$$\psi(\delta^2, \bar{b}) \triangleq (\bar{b}^2 - \delta^2)\phi(\delta^2, \bar{b}) = g \qquad (18)$$

where $g \triangleq 2(1 - c^{-1})\sigma^c$ *and*

$$\phi(\delta^2, \bar{b}) = \tfrac{1}{2}\bar{b}^{-1}\left\{(\bar{b} + \delta)^{c-1} + (\bar{b} - \delta)^{c-1}\right\} > 0$$

Note that when $1 < c < 2$, $\phi(\delta^2, \bar{b})$ *is strictly decreasing in* δ^2. *The cusp points also need to satisfy*

$$D\psi(\delta^2, \bar{b}) = 0$$
$$\Leftrightarrow (c - 1)(\bar{b}^2 - \delta^2)\left\{(\bar{b} + \delta)^{c-2} - (\bar{b} + \delta)^{c-2}\right\} = 2\delta\left\{(\bar{b} + \delta)^{c-1} + (\bar{b} - \delta)^{c-1}\right\}$$

Note in particular that for each value of $\bar{b}$ *there is always a cusp point at* $(\delta, \rho, g) = (0, 0, \bar{b}^c)$ *and the splitting factor of such a cusp is* $b^{-c} - g$: *largest when the difference between the campaign point and mission point is large and 'when the uncertainty* σ *is small. When* $0 < c < 1$, $g < 0$ *but* $\psi(\delta^2, \bar{b}) > 0$ *so no fold points exist. As p increases, the best course of action jumps when* $\rho = 0$ *from pure circumspection a to the value b of pure combat. When* $c = 1$, *the stationary points are*

given by those value, unique functions of the parameters satisfying $\delta_c = d_c - 1/2(a+b) = \rho/\sigma$ *and this again is always a minimum except when* $\rho = 0$ *when all intensities in* $[a, b]$ *are equally good. Finally, when* $1 < c \leqslant 2$ *because* ψ *is decreasing in* δ^2 *and* $g > 0$*, there is a single pair of stationary points* $(-\delta^*, \delta^*)$*—coinciding when* $\delta^* = 0$*—lying on fold points if and only if*

$$\psi(0) = \bar{b}^c = (1/2(b-a))^c \geqslant (2(1-c^{-1})\sigma^c) = g$$

It can easily be checked that for a given $\bar{b}$ *there is a single cusp point at* $(\delta, \rho, g) = (0, 0, \bar{b}^c)$*. In the special case when* $c = 2$*, the fold points are given by*

$$\delta^2 = \bar{b}^2 - \sigma^2$$

There are therefore no fold points if $\bar{b}^2 = 1/4(b-a)^2 < \sigma^2$*, while if* $1/4(b-a)^2 \geqslant \sigma^2$ *the fold points are given by*

$$d = 1/2(a+b) \pm \sqrt{1/4(b-a)^2 - \sigma^2}$$

Differentiating and solving gives that the cusp point satisfies

$$1/4(b-a)^2 = \sigma^2, d = 1/2(a+b)$$

The distance between the campaign and mission point is therefore again central here. See Smith (1979) for further analyses of the geometry of this special case and its generic analogues. Note that this case is used to explain and categorize the results of two battle group exercises we discuss in Dodd et al (2006).

Like in the γ example above, the assumption of equality in the uncertainty parameter for the two distributions is not critical in the example above in the sense that the underlying geometry can still be described in terms of s continuum of cusp points and details of their exact coordinates for the case $c = 2$ can be found in Smith (1983). It turns out the richest geometry is obtain in the equal variance case, and when the uncertainty associated with one of the objectives is much higher than the other the large uncertainty objective tends to get ignored in favour of the other and the problem tends to degenerate.

We end by elaborating the first example to analyse the geometry of non-boundary scenarios of this type. We note that as we move away for the boundary, cusp catastrophes like those appearing in the last two examples are exhibited in this example as well.

Example 7 (General Beta Case) *For* $i = 1, 2$*, let* $P_i(d|\chi)$ *be the density of* $2X_i - 1 + (-1)^i c$ *where* X_1 *has a beta* $B(\alpha_i, \beta_i)$ *density given in the earlier example and* $|c| \leqslant 1$*. Then* $I(\chi) = [|c|-1, 1-|c|]$ *and the scenario is primal when* $c > 0$*, dual when* $c < 0$ *whilst when* $c = 0$ *we have a linear transformation of the boundary case of the last example. Writing* $\gamma_i = \alpha_i - 1$*,* $\varepsilon_i = \beta_i - 1$*,* $i = 1, 2$*. The Equation (8) becomes*

$$\gamma_2 \log(1+d+c) + \varepsilon_2 \log(1-d-c) - \gamma_1 \log(1+d-c) - \varepsilon_1 \log(1-d+c) = \rho''$$

where

$$\rho'' = \rho + \sum_{i=1,2} \log\Gamma(\alpha_i) + \log\Gamma(\beta_i) - \log\Gamma(\alpha_i + \beta_i) + (\gamma_2 + \varepsilon_2 - \gamma_1 + \varepsilon_1)\log 2$$

Differentiating and reorganizing, we find that in the fold points in $I(\chi)$ *must satisfy the cubic*

$$\sum_{j=0}^{3} c_j d^j = 0$$

where

$$\begin{aligned} c_0 &= (1-c^2)[(\varepsilon_1 + \gamma_2)(1-c) - (\gamma_1 + \varepsilon_2)(1+c)] \\ c_1 &= (\varepsilon_1 - \gamma_2)(1-c)^2 - (\gamma_1 - \varepsilon_2)(1+c)^2 \\ c_2 &= -(\varepsilon_1 + \gamma_2)(1+c) + (\gamma_1 + \varepsilon_2)(1-c) \\ c_3 &= \gamma_2 + \varepsilon_2 - \gamma_1 + \varepsilon_1 \end{aligned}$$

This situation is therefore slightly more complicated than the boundary on we discussed earlier, because there is the possibility that two *local and potentially competing maxima appear in the interior of* $I(\chi)$*. However, when a commander is comparably certain of the effect of chosen intensity on mission and campaign objectives, then* $\gamma_1 + \varepsilon_1 = \gamma_2 + \varepsilon_2$ *the fold point becomes quadratic and we recover the geometry of the single canonical cusp/dual cusp catastrophe. After a little algebra, the cusp points related to the modes through the equation.*

$$\frac{\xi_2 - \xi_1}{\xi_2 + \xi_1} = c^2$$

When $c = 0$ *our earlier case—this equation degenerates into requiring* $P_1 = P_2$*—but otherwise such cusp points exist and are feasible whenever* $\xi_2 > \xi_1$*. This demonstrates how our original example can be generalized straightforwardly away form convexity to a situation where compromise appears as an expression of the cusp catastrophe.*

6. Discussion

There are several conclusions, concerning C2 regulation, that can be drawn from this analysis about how to organize, train and communicate intent and freedoms for decision making to commanders; indeed, a number of these conclusions are already being accepted as good practice under the principles of command agility. Here, we will

assume that commanders face a scenario where both P_1 and P_2 are twice differentiable and unimodal.

1. Whenever appropriate and possible, mission statements and campaign objectives should be stated in such a way that they are resolvable so that well-trained rational commanders can acknowledge and safely achieve compromise.
2. When a situation cannot be presented or acknowledged as resolvable, then, within agile planning to devolve decision making, commanders should be presented with a pseudo-resolvable scenario. The first of two conditions required for this is that the scenario is primal. This means that the commander can perfectly address the campaign objectives while still having some possibility of completing the tactical mission to some degree of success and there is a level of intensity appropriate for attaining the tactical mission objectives, which also can be expected not to totally jeopardize the campaign. It will often be possible to make a scenario primal simply by the way the two objectives are communicated to the commander, although it may involve some innovative option-making. The second requirement is to control the modes of the mission and campaign points so that the intensity with the greatest incremental improvement on mission success occurs at a value ensuring maximal campaign integrity also that the greatest incremental improvement on campaign success occurs at a value ensuring maximal mission. A rational commander will then choose to compromise between the two objectives. The actual compromise point will depend on each commander's individual training, personality and emotional history, but the careful matching of contiguous commanders should help to ensure coherence.
3. When neither of the two scenarios described above are achievable, then in most cases, provided the mission point is lower than the campaign point, the devolved commander can still be expected to compromise and not to be faced with contradiction. In this case, a C2 regulatory agent must be prepared to expect lower levels of contiguity but coherence can still be managed by carefully considering the commanders' capacity to deal with stresses. In particular to encourage compromise, mission statements must allow for there to be an option that scores at least half as well as the best option for mission and at least half as well for campaign objectives. Note that if it is made clear that partially achieved success in the two objectives is more highly rated, then the likelihood of compromise is increased.
4. Problems of lack of contiguity and contradiction can be expected to occur if the mission point is much higher than the campaign point. If a C2 regulatory agent still plans to devolve in these cases, then it must endeavour to keep the distance between the mission and campaign points as small as possible, since this will limit the extent of the discontiguity and contradiction (see the analysis of the last section).
5. The most undesirable scenarios are those that are unresolvable or pseudo-unresolvable. In these cases, the focus falls on ρ and therefore, unless the intensity associated with pure combat is close to that for pure circumspection, the training, deployment and personality of individual commanders will become crucial. The C2 settings are then most stable if a top-down style is adopted.

All these points rely on the assumption of commander rationality. In Dodd *et al* (2003, 2006), we detail results from two experiments studying how experienced personnel respond to conflicting scenarios. The first was a mission where there was high risk of casualties. The second was a potential threat to a civilian convoy where the commander had to balance the efficacy of defence from attack and a negotiated passage. Participants were then encouraged to document their decision processes. The commanders often reasoned differently, but interestingly all choose courses of action consistent with the rationality described above. Perhaps one of the most interesting findings was that confidence in succeeding in the objectives—mainly reflected in the choice of ρ—had a big influence on course of action selection. Conclusions from these experiments, aided by the implementation of the ideas above, have informed procurement of command information systems (Saunders and Miles, 2004). Of course in real time a commander can only evaluate a few possible courses of action (Moffat, 2002; Moffat and Witty, 2002; Perry and Moffat, 2004), but we argue in Dodd *et al* (2006) that this does not invalidate the approach above, it just approximates it. Thus, both from the theoretical and practical perspective, this rational model—where C2 regulation assumes its commanders choose what is rationally consistent with their individual nature, experience and competencies is a good starting point for understanding C2 regulatory mechanisms and the needs for formal education into C2 organizational issues and for command training and selection.

7. Further application outside military domain

This work has an experimental foundation in military command decision studies, but it is not limited to situations of military hierarchy and mission command. Indeed, the findings can be applied to any situations where there may be uncertainty and where there is potential for contention in management objectives. Such conditions are common within many organizations today as they struggle to balance risks against a need to expand into new uncertain markets. The two key principles, which underlie the theory, of maintenance of contiguity and avoidance of

contradiction are as relevant to management as they are to military C2. Appropriate placing of decision authorities and responsibilities within organizations, according to the prevailing circumstances as a whole, could determine the difference between commercial success and failure.

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Appendix

Writing $u[0,\boldsymbol{\lambda}]=\inf_{d\in D}\{\bar{U}(\boldsymbol{d}|\boldsymbol{\lambda})\}$ and $u[1,\boldsymbol{\lambda}]=\sup_{d\in D}\{\bar{U}_i(\boldsymbol{d}|\boldsymbol{\lambda})\}$, to obtain Equation (3).

Note that $\bar{U}(\boldsymbol{d}|\boldsymbol{\lambda})$ is an increasing linear transformation of $\alpha_1^0(\boldsymbol{\lambda})U_1^0(\boldsymbol{d}|\boldsymbol{\lambda})+\alpha_2^0(\boldsymbol{\lambda})U_2^0(\boldsymbol{d}|\boldsymbol{\lambda})$ where, for $i=1,2$,

$$U^0(\boldsymbol{d}|\lambda)=\{U_i^0(d,\boldsymbol{d}_i^*(d)|\boldsymbol{\lambda})-u[0,\boldsymbol{\lambda}]\}\{u[1,\boldsymbol{\lambda}]-u[0,\boldsymbol{\lambda}]\}^{-1}$$

$$U_i^0(\boldsymbol{d}|\lambda)=\{\bar{U}_i(\boldsymbol{d}|\boldsymbol{\lambda})-u[0,\boldsymbol{\lambda}]\}\{u_i[1,\lambda]-u[0,\boldsymbol{\lambda}]\}^{-1}$$

and

$$\alpha_i^0(\boldsymbol{\lambda})=a_i(\boldsymbol{\lambda})u_i[1,\boldsymbol{\lambda}]u[1,\boldsymbol{\lambda}]^{-1}.$$

Note that these renormalizations simply ensure that $\alpha_1^0(\lambda)+\alpha_2^0(\lambda)=1$, $\sup\ U^0(\boldsymbol{d}|\lambda)=\sup\ U_1^0(\boldsymbol{d}|\lambda)=\sup\ U_2^0(\boldsymbol{d}|\lambda)=1$ and $\inf\ U^0(\boldsymbol{d}|\lambda)=\inf\ U_1^0(\boldsymbol{d}|\lambda)=\inf\ U_2^0(\boldsymbol{d}|\lambda)=0$.

For each fixed value of d, a rational commander chooses the decision $\boldsymbol{d}_i^*(d)$ maximizing $U'_i(\boldsymbol{d}|\boldsymbol{\lambda})$, $i=1,2$, respectively, and then chooses d so as to maximize

$$\alpha_1^0(\boldsymbol{\lambda})P_1(d|\boldsymbol{\lambda})+\alpha_2^0(\boldsymbol{\lambda})(1-P_2(d|\boldsymbol{\lambda}))$$

where $P_1(d|\lambda)=U_1^0(d,\boldsymbol{d}_1^*(d)|\boldsymbol{\lambda})$ and $P_2(d|\lambda)=1-U_1^0(d,\boldsymbol{d}_2^*(d)|\boldsymbol{\lambda})$. On substitution this can be seen to be maximized when $V(d|\boldsymbol{\lambda})$ of Equation (3) is maximized.

Theorem 8 *If $V(d_0^*(\lambda),\lambda)$ is continuous in d at all values $\boldsymbol{\lambda}\in\Lambda$ and $d^*(\boldsymbol{\lambda}_0)$, defined above, is unique and there exists, for a fixed value of $\boldsymbol{\lambda}_0$, an $\eta'>0$ such that $V(d,\boldsymbol{\lambda}_0)$ is strictly increasing in d when $d^*(\boldsymbol{\lambda}_0)-\eta'<d<d^*(\boldsymbol{\lambda}_0)$ and strictly decreasing when $d^*(\boldsymbol{\lambda}_0)<d<d^*(\boldsymbol{\lambda}_0)+\eta'$, then $d^*(\boldsymbol{\lambda}_0)$ is continuous in $\boldsymbol{\lambda}$ at $\boldsymbol{\lambda}_0$.*

Proof: For $\delta>0$, let $V^*(\boldsymbol{\lambda}_0)=\sup_{d\in D}\{V(d,\boldsymbol{\lambda}_0)\}$ and $A(\boldsymbol{\lambda},\delta(\eta'))=\{d\colon V(d,\boldsymbol{\lambda})>V^*(\boldsymbol{\lambda})-\delta\}$ where

$$\delta(\eta')=\max\{V(d^*(\boldsymbol{\lambda}_0),\boldsymbol{\lambda}_0)-V(d^*(\boldsymbol{\lambda}_0)-\eta',\boldsymbol{\lambda}_0),\ V(d^*(\boldsymbol{\lambda}_0),\boldsymbol{\lambda}_0)-V(d^*(\boldsymbol{\lambda}_0)+\eta',\boldsymbol{\lambda}_0)\}$$

Then, from the uniqueness of $d^*(\boldsymbol{\lambda}_0)$ and the monotonicity conditions above, for all $\varepsilon>0$, there exists an $\eta'(\varepsilon)>0$ such that $A(\boldsymbol{\lambda}_0,\delta(\eta'))\subseteq B(d^*(\boldsymbol{\lambda}_0),\varepsilon(\eta'))$ where $B(d^*(\boldsymbol{\lambda}_0),\varepsilon)$

is an open ball centred at $d^*(\boldsymbol{\lambda}_0)$ of radius ε. By the continuity of $V(d, \boldsymbol{\lambda}_0)$ at $(d^*(\boldsymbol{\lambda}_0), \boldsymbol{\lambda}_0)$, for all $\varepsilon > 0$ there exists an $\eta(\omega) > 0$ such that if $||\lambda_0 - \lambda||_0 < \eta$ then $|V^*(\boldsymbol{\lambda}_0) - V^*(\boldsymbol{\lambda})| < \varepsilon$. Thus

$$\begin{aligned} d^*(\boldsymbol{\lambda}) \in & A(\boldsymbol{\lambda}, \delta) \subseteq \{d : V(d, \boldsymbol{\lambda}_0) > V^*(\lambda) - \delta - \omega\} \\ & = A(\boldsymbol{\lambda}_0, \delta + \omega) \subseteq B(d^*(\boldsymbol{\lambda}_0), 2\varepsilon) \end{aligned}$$

which implies that, for all $\varepsilon > 0$ there is an $\eta''(\varepsilon) = \min [\eta'(\varepsilon), \eta(\omega)] > 0$ such that if $||\boldsymbol{\lambda} - \boldsymbol{\lambda}_0||_0 < \eta$, $|d^*(\boldsymbol{\lambda}) - d^*(\boldsymbol{\lambda}_0)| < 2\varepsilon$: ie $d^*(\boldsymbol{\lambda})$ is continuous at $\boldsymbol{\lambda}_0$. □

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A Theory of Choices:

Melding black swans, butterflies and swallowtails

Lorraine Dodd
Centre for Applied Systems Studies
Cranfield University
Defence Academy of UK
L.dodd@cranfield.ac.uk

The novel theory presented here encompasses the disciplines of anthropology, psychology, mathematics, organizations, institutions and social complexity. The theory goes beyond social, cultural and organizational theory as it embodies catastrophe theory and involves sense-making, decision-making and choice-making under conditions of social and environmental complexity (i.e. intricate couplings and interrelationships as well as increasing ranges of connections and interactivities).

1 Introduction

A previous ICCS (2008) paper [1] discussed the impact of going from closed eyes and mind to open eyes and mind; in particular how thinking more openly about complexity (i.e. holding "wide attention" [2] through open, reflective thinking [3] and creative thinking) may help to provide support and make it possible and bearable.

This paper presents a formal mathematical foundation for developing new ways of seeing choices (i.e. options relating to focus of attention, interpretations of a situation, and courses of action, adaptation and/or transformation), which can help by providing conceptual support when there is both a complex social mix and a challenging degree of open-endedness, uncertainty, ambiguity, confusion, volatility, contention and unknowns in the situations being faced. (Note that the complex mix can extend to objects and agents that form part of the social mix but are not necessarily human.)

The theory provides insight and supports reasoning about the challenges brought about by differences in ways of sensing, observing, noticing, interpreting, modeling, assessing, adapting and acting in our increasingly open and complex world. As such it addresses such questions as:

1. Where do our choices and the associated limits on choices emerge from and how do the limits on choice reflect back on our states of mind and focus of attention?

2. Why and how do the nature and scope of our choices tend, often dramatically, to shape the emergent behaviors within and between complex adaptive systems?

The world is full of tipping points and cliff edges but it is not clear what forms the slow dynamic that moves and shapes the underlying surface responsible for decisions and chosen actions. This theory could help with early warning of impending cliff edges in what often seems to be an otherwise smooth progression; at least it will help to prepare for making the most of the potential cliff edges as they offer up opportunities for transformation, structural change and growth.

1.1 Mathematical basis in Catastrophe Theory

The mathematics develops from the nature of variety in different people's *principles of being* that translate across into priorities for doing (and preferences for not doing). In particular, the theory expresses what might affect those priorities when a particular complex social mix presents a need to resolve the principles of being; that is, as and when there is a need for coexistence, collaboration and cooperation.

The mathematical essence is drawn from Catastrophe Theory [4], [5], which links four underlying shaping parameters to 'control regions' relating to different decisions and resultant behavioral actions.

2 Towards a theory of choices

2.1 The subjective nature of individual choices

How people and entities might see, hear, sense, feel, interpret, discern, assess, adapt and act in their world is shaped and conditioned by the nature and scope of the options for choice that appear[1] to be open to them at the time of selection. These options for choice will be termed "choose-ables" to emphasize their subjectivity. These choose-ables could be options for taking action, for making sense of situations, for where to focus or place attention, of what to believe, of direction or intent, etc. These tend to be coupled[2] such that if, say, there are only two options for action then there will tend to be just two choose-ables 'open' for interpreting what is happening in the immediate surroundings; so if the events or objects of interest in the immediate surroundings are seen as and interpreted to be A rather than B then choose to do X, otherwise choose to do Y.

Choose-ables have often also been pre-set through restraints and constraints determined by the individual or institutional or organizational context and may be then tempered by the outlook of the chooser to their wider scope of relationships and immediate needs. For example, one may be tempted to act outside the rules if it will secure useful relationships or satisfy a critical need. The scope of choose-ables can be (often severely) constrained by institutional norms and also through individual restraint to behave cooperatively and 'normally'. This mix of contextual and textual constraints and restraints provides a rich texture through which to study what is happening at the boundaries between the context and the text (e.g. Alexander's concept of "Thick Boundaries"). This then begets the theme for a theory of choices.

2.2 Culture Theory

Culture theory works to complement Catastrophe Theory, and the key essence is drawn from work by Michael Thompson and Mary Douglas [7], [8]. Four attractor states of being are proposed: hierarchist, individualist, egalitarian and fatalist. Each has a representative choice function, which is depicted in Figure 1 as a mouth shape. So the assumption is that each cultural attractor state has a correspondingly different way of choosing and the representative choice functions embody the different natures of the belief and preference functions relating to the attractor states. For example, a fatalist will tend to have a more flattened preference function (in the extreme it might be a flat line as in Figure 1) compared with those corresponding to the other attractor states. This flattening of the preference function then reduces the concern for predicting the future in material terms because "what happens happens". On the other hand a hierarchist

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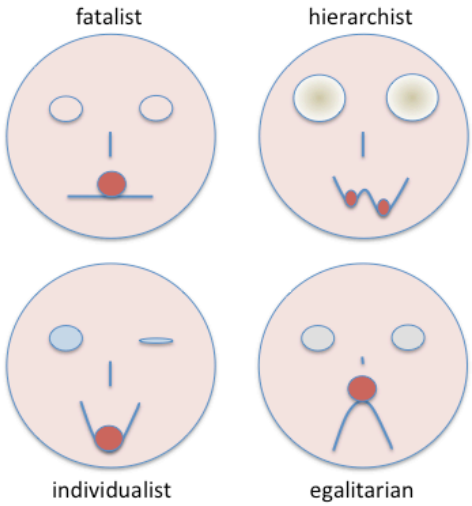
[1] This naturally suggests that the influences flow both ways between the sensing, discerning, deciding, etc functions and the choices seemingly open for choice; so having closed mind and eyes tends to close-off options for choice but also not being able to see or create more open options for choice tends towards finding comfort in closed eyes and minds.

[2] The strength and intricacy of this coupling will depend on the prevailing conditions (e.g. time criticality, pressure to act, etc) and the nature of the chooser (i.e. is it a machine, an organism, a brain with a large cortex, an individual within an established institution, etc).

will tend to have concern for not only their own preference function but at least one other preference function (often one level up or down).

So the hierarchist is seen to be considering their options for action according to at least two different viewpoints, being held at the different levels in the hierarchy. For instance, what might be locally deemed 'good' to do[3] may not be as 'good' when viewed more globally; hence the curly mouth with the two minima at different levels.

The individualist tends to hold a singular view of what constitutes the 'best' choice; hence the single minimum depicted as a smiley mouth. The hierarchist and the individualist can be seen to be two extremes of a continuum (following an imagined diagonal line from top-right to bottom-left in Figure 1, along which the concern or openness to others' viewpoints diminishes). This has resonance with Jacobs' Guardianship and Commercialism [9].



Note that these are attractive states of mind/being adopted due to grid-group 'couplings'.
These restrict choices for course of action and then influence state of mind/eyes.

Figure 1: The four faces, adapted from Thompson, the mouths representing the different nature of their choices.

The egalitarian strives to maintain an implicit, presumed sense of what is good for all and holds tightly to a need for stability within the status quo that maintains this position; hence the determined mouth represents a ball precariously balanced on a constructed hill and choices revolve around actions and behaviors that maintain and uphold stability. The fatalist has no care about what or how to choose personally; hence the mouth represents a flat line along which he might

[3] In his ICCS plenary in 2008 Ray Jackendoff presented eight aspects of 'good-ness' which are useful when we consider different viewpoints and preference functions corresponding to the different attractor states.

be moved but with focus also on a workable degree of stability and regulated normality. The egalitarian and the fatalist can be seen to be two extremes of a continuum (following an imagined diagonal line from bottom right to top left in Figure1, along which the need for concern about controlling and normalizing future material events and outcomes diminishes in importance).

It is not clear what defines the nature of the surface upon which the attractor states might be imagined to 'sit'. Put another way the attractor states could be seen to be emergent properties of a diverse cultural mix, given the implicit boundaries and limits on ways in which varieties of choosers are able to relate to their surroundings and the nature of their choose-ables[4]. This will be discussed in more detail when we have considered the role that Catastrophe Theory may play as a way to describe how movement between the attractors may be being governed or understood.

2.3 Four parameters of choice, cooperation and co-existence

The four Catastrophe Theory surfaces: the fold, cusp, swallowtail and butterfly are described by four parameters. These parameters could be described as representing certain elements of choice as follows:

a: is referred to as a normal factor and can represent whatever elements are chosen to monitor and maintain normalizing behaviors, outcomes, measures, indicators, etc. This can then focus choose-ables down to being only those that are seen to steady[5] and help to normalize.
b: is referred to as the splitting factor and can represents the degree of confusion or discomfort felt due to a situation being ambiguous, ambivalent and/or pertaining to two or more conflicting preference functions.
c: represents two broad elements of contention based on attitudes to assessment: (describing the swallowtail and butterfly catastrophe surfaces respectively)

> c1: differences in projected futures (e.g. short-termism vs long-term view) and beliefs in possible/likely/probable futures;
> c2: differences in perspectives and measures of motivation (or loss/gain).

3 Four catastrophe surfaces

Let's now assume that choices are made and decisions are taken according to some imagined principle of viability or sustainability such that any chooser or decider (or deciding agent or cell, etc) is striving where possible to preserve any such principle, whatever is the chooser's scope of interest and concern. For instance, in a particular setting, such a principle could be imagined to be

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[4] The chooser's freedom and capacity to be able to change their set of choose-ables is a key question here and leads into the basis for the differentiation and integration when discussing the catastrophe surfaces.

[5] Geoffrey Vickers in his book "Freedom in a Rocking Boat: changing values in an unstable society" (1972) captures the essence of the difficulty here in trying to open-up the range of choose-ables, when the focus is on stabilizing and normalizing.

preserving what might maintain the likelihood of loss (e.g. of life, money, power, stability, reputation, etc) at as low a level as possible.

3.1 Fold

If there is no room for concern for anything other than a need for normalizing and stabilizing, even to the exclusion of own values and identity, then we are working more along the continuum between egalitarian and fatalist (i.e. the upturned mouth or the flat line extreme) and the relevant catastrophe surface is the fold catastrophe. This is dependent only on the first parameter (a: the normal factor). A useful descriptive representation of the nature of choice and the set of choose-ables (which necessarily precludes any capacity or freedom to choose to change the set of choose-ables) is a fold catastrophe. Here there is one option for action that holds up to a point and the nature of the options for choice relate to those of fatalist through to egalitarian.

3.2 Cusp

If in addition to concern for normalizing and stabilizing, there is also a concern for one's own (and maybe others' in one's close alliance) values and perspectives, then we are working along the continuum between individualist and hierarchist (i.e. the wiggly mouth or the smiley mouth at the lower extreme) and the relevant catastrophe surface is the cusp catastrophe. This is dependent on the first two parameters (a: the normal factor and b: the splitting factor). Here the splitting factor describes the way in which the set of choose-ables goes from a smooth and relatively open set, through a singularity to a bifurcated set of two choose-ables (increasingly extreme; e.g. hyper and hypo actions), both of which offer stable local minima. Here the chooser is left with whatever option the prevailing conditions have led to until a tipping point is reached, when a tiny change results in a jump from one extreme to the other.

3.3 Swallowtail

If in addition to the previous two concerns there is further concern for managing differences in beliefs and cares regarding projected future outcomes, then we are trying to open not only their eyes to others' views but also to open their minds to others' models of interpretation and projection. We are here in the swallowtail (parameters a, b, c1) where the proverbial "black swan" phenomenon [10] is telling of what happens when eyes may be opened by 'black swan' events; but, unless minds are opened to broaden interpretative models and frames of reference, all will return to the original comfort of closed eyes and closed options.

3.4 Butterfly

If in addition to the previous three concerns, there is further concern for others' contentious differences in preference, perspective and measures of success or failure then we are imagining trying to find balance and consensus and the relevant catastrophe surface is the butterfly (parameters a, b, c1 and c2). The key to staying open is to throw light onto the choose-ables. This allows us to prepare for and therefore see the existence of a third surface, which is the key to ongoing adaptation and mutually beneficial transformation.

4 Concluding remarks

A combination of the concepts underlying the four faces of culture theory with the four parameters of catastrophe theory then provides us with a theory of choices. So, as awareness narrows and acknowledgement of a broader set of preferences and beliefs begins to wane (or indeed may never have been there at all in many cases), the need to have freedom to choose when and how to make changes to one's set of choose-ables is also diminished. Different complex adaptive systems will tend to have different freedoms for choice; that is, selecting from their fixed set of choose-ables through to choosing between ways of changing their sets of choose-ables. Where anyone or any system might tend to be, in terms of any one (or more) of the attractor states, will help to understand why different sets of choose-ables tend to exclude or include any considerations of the four parameters; a, b, c1 and c2. Having such a theory of choices, or at least a basis for a conceptual framework, may then help in understanding why certain complex adaptive systems (and in particular certain 'cultural' mixes of them) can tend to exhibit behavioral syndromes, such as "black swans" and hints at why we need to open eyes and minds in preparation for times when opportunities for change and transformation are ripe and where we can be ready with some support based on the mathematics of swallowtails and butterflies.

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18th ICCRTS
"C2 in Underdeveloped, Degraded and Denied Operational Environments"

ORDERS OF C2 AGILITY AND IMPLICATIONS FOR INFORMATION AND DECISION-MAKING

Primary topic: Topic 1: Concepts, Theory, and Policy

Alternate topics: Topic 2: Approaches and Organizations

Topic 4: Collaboration, Shared Awareness, and Decision Making

Authors:

Lorraine Dodd
Cranfield University
Defence Academy of the United Kingdom
Shrivenham
Wilts SN6 8LA
United Kingdom

Geoff Markham
QinetiQ
St Andrew's Road, Malvern
Worcestershire WR14 3PS
United Kingdom

Point of Contact:

Lorraine Dodd
Cranfield University
Defence Academy of the United Kingdom
Shrivenham
Wilts SN6 8LA
United Kingdom
(+44) 1793 785761
L.dodd@cranfield.ac.uk

ORDERS OF C2 AGILITY AND IMPLICATIONS FOR INFORMATION AND DECISION-MAKING

ABSTRACT

In a paper at 17th International Command and Control Research and Technology Symposium (ICCRTS), different forms of Command and Control (C2) agility were related to different forms of time. In this paper we broaden this idea to consider *orders of agility*. An immediate consequence is the clarification of the interplay between continuity and change, as seen in all manifestations of agility and, in particular, in discussions of resilience.

Orders of agility also invite the re-examination of conceptions of value in informing decision-making, leading to the exposition of a hierarchical model of nested decision-making and decision-taking. Further, if we take a purposive definition of information, being that which is required to enable decision-making, then different types of information, and indeed different definitions of information, can also be related to this hierarchical scheme.

Thus, model of orders of agility provides a unifying scheme for ostensibly diverse and incompatible interpretations of decision-making and information. It also gives greater confidence that different conceptions of value and assessment measures can be organized systematically, rather than being subverted by being mapped on to inappropriate solution-driven preferences. Thus orders of agility become a useful source of rigour in the design of C2 experiments, the formulation and exercise of simulations and the assessment of C2 capability.

INTRODUCTION

Agility is a theme which arises in relation to a range of endeavours in the military and the non-military world, appearing either in accounts of practical experience or in statements of aspirations. Specifically, C2 agility is an essential capability attribute for military forces if they are to be able operate effectively in the context of future operations characterised by two forms of complexity:

- situational complexity, reflected in situations with:
  - no obvious precedents;
  - uncertain outcomes;
  - shifting objectives;
  - issues with measuring progress.
- organizational complexity, when people are working with different levels and degrees of:
  - co-operation and forms of coupling with partners;
  - unanticipated alliances;
  - interactions between multiple Instruments of Power;
  - dynamic synthesis and construction of working practices at the 'point of use'.

These issues have been the explicit focus of the United Kingdom (UK) Ministry of Defence (MOD) Command Information Battlespace Management (CIBM) Research Programme's Task 10 (C2 agility) and an implicit focus of Task 9 (Shared Situational Awareness in the context of the Integrated Approach). An earlier paper derived from Task 10 [1] was presented at 17th ICCRTS ("Operationalizing C2 Agility") in June 2012, focussing on the different forms of time

which are exhibited in, or are relevant to, the exercise of agility. The purpose of the current paper is to extend the earlier work to make more explicit the impact of these different forms of time on decision-making, where this includes any decision that considers potential changes of any kind: this includes courses of action, ways of organizing, and means of maintaining communication. The paper also considers the impact on information, which can be viewed in the most general terms as a conditioner of decision-making.

Structure of this paper

The first section of this paper reviews the key elements of the earlier paper on forms of time [1], which leads us to the idea of *orders of agility*, which is the central idea in the paper.

The second section moves on to discuss decision-making, and in particular the creation, tasking, configuration, execution and reporting of *decision systems*. These are organizational constructs which will reflect all of the dimensions of organizational behaviour (process, structure, participation, knowledge, etc.). So, for example, a planning team which has been tasked to develop a course of action can be viewed as a decision system. The aim is to use the principles of orders of agility to understand the construction of the 'decision space' within which decision systems are operating.

Finally there is a brief observation on the role of information in determining, conditioning and reflecting the behaviour of decision systems, an observation which is supported by a longer discussion in an Appendix.

FROM FORMS OF TIME TO ORDERS OF AGILITY

Whilst the accounts presented of agility differ widely, common to all of them is the interplay between continuity (i.e. regarding preservation of identity and forms of order) and change (i.e. regarding preservation of requisite variety and diversity). Both continuity and change imply some notion of time, but different concepts of agility adopt different uses of time, and indeed different forms of time.

The importance of the interplay between the two is reflected in the concept of being *chaordic*. Dyer and Schafer [2] cite Dee Hock[1], who used the term to describe the need for organizations to be both chaotic and ordered to achieve agility. Chaos allows for initiative to flourish (i.e. use of personal agency with a hint of tolerance for generative[2] instability and learning through failure), whilst being held within a system of overall co-operation (i.e. an appropriate holding structure for such agency in the form of Jaques' sense of requisite organization [3]).

The work on requisite organization also draws on Jacques' earlier work [4] in which he presents two dimensions (or forms) of time, and asserts that "In the form of time is to be found the form of living". These two forms of time, successive and intentional, can be related to the two Greek notions of time:

- *kairos* - opportune timing, more about time in between;
- *chronos* – sequential, according to an assumed chronology.

Put simply, kairos is about qualitative moments of opportunity whereas chronos is about quantitative, linear, clock-tick time. So kairos relates more to Jaques' successive dimension of time as it embodies elements of quality (i.e. assessment of "success" or appropriateness),

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[1] Former president of VISA International

[2] Those that are organizationally adept, open to experimentation, fast learners and appliers of new knowledge, and team players [2].

whilst chronos relates more to Jaques' intentional dimension of time as it covers looking forward in time (i.e. short-term or long-term projections).

In the earlier paper [1], we developed this insight to present a number of different images of time (along different dimensions of human and organizational activity). The paper considered:

- operational responses to changes in the environment: options summarised as *react, anticipate shape*;
- observing, reporting and interpreting events and situations;
- making decisions, or moving (in organizational terms) the point at which decisions are made;
- different knowledge types in use in making decisions:
  - technical skills and practices: *techne*;
  - teachable knowledge: *episteme*;
  - experiential knowledge learnt through felt experience: *phronesis*;
  - conjectural knowledge and cunning learnt through complexity: *metis*.

These are summarised in the consolidated view in Figure 1(a), which invites us to recognise some similarities in the relationships between the options presented by the different dimensions.

As a bold and intuitive attempt to put the earlier discussions into a common framework, Figure 1(a) runs the risk of encouraging over-interpretation. The figure is not suggesting that 'anticipation' correlates with 'classification', simply because both are drawn at approximately the same radius. The point is more that the shift from reaction to anticipation is a change in *order*, rather than a change in detail, with a resultant change in the form of time (i.e. away from *chronos* towards something rather more akin to *kairos*). A similar change is exhibited in the shift from merely observing and reporting events to a focus on classification in which, again, events may begin to be abstracted away from their original chronometer settings and viewed against different temporal logics (e.g. A happened after B when conditions C were prevailing).

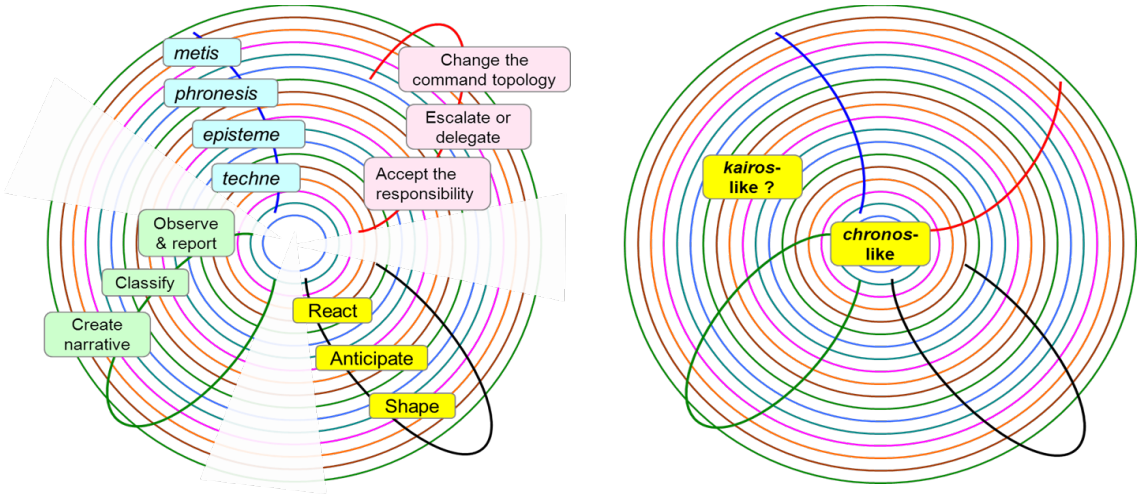

Figure 1: Consolidated views of forms of time

A number of cycles become evident in the consolidated Figure 1(a), of which the innermost ring is perhaps the most familiar to a military C2 audience: it is effectively the OODA loop applied to the task of an operator (e.g. a platform commander) responding to the situation with which he is engaged. There is a chronos-based time-measure associated with how fast the OODA loop can be executed, relative to the rate of change of the operational environment.

Moving outwards in radial terms, what the cycle begins to describe is the 'OODA loop for HQ', which is obviously much richer than for platform C2, which is why a more general model of sensemaking might be more appropriate as the move is away from response activity towards adaptation. Here, then, the reservations which many have expressed in relation to the OODA loop can be characterised in terms of the need to accommodate the shift from chronos to kairos, as depicted in Figure 1(b); something which can easily be obscured in conventional 'process-like' or 'feedback loop' images and models of C2.

But each of the dimensions of agility also has its own cycle, whereby the effects of higher-order processes filter back down to lower-order activities. This is exemplified by institutional learning, as shown in Figure 2.

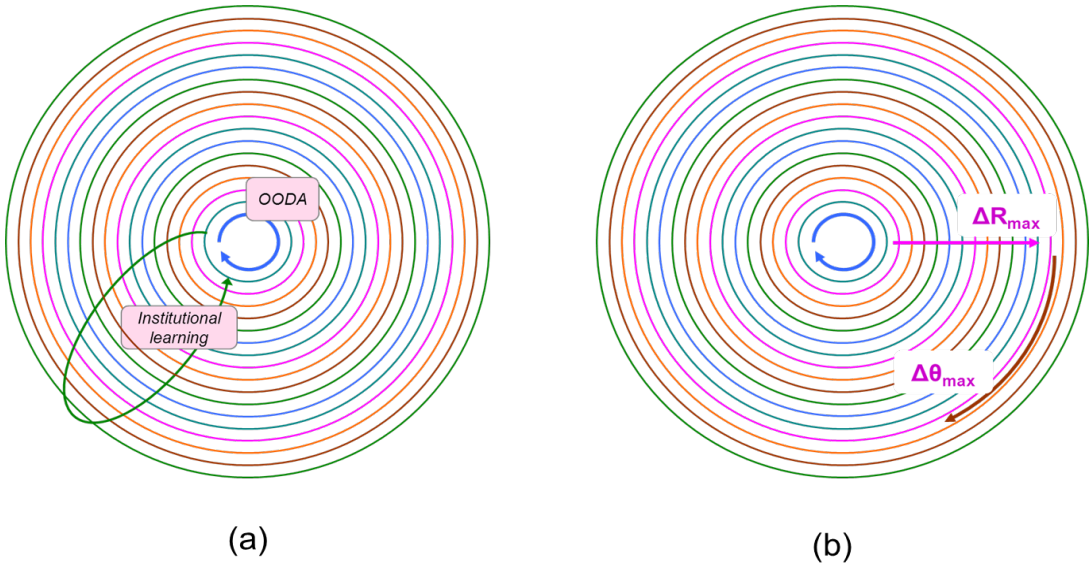

Figure 2: Examples of cycles, and higher-order changes in the form of time

We are also invited to consider what forms of agility are involved in moving around the backdrop to Figure 1 and Figure 2(a). This reveals (at least) the two qualitatively different forms of movement identified in Figure 2(b), where:

- ΔR_{max} represents a shift of focus, e.g. from reacting to anticipating;
- $\Delta \theta_{max}$ represents a shift of emphasis between observing, interpreting and taking action.

Each of these shifts is accompanied by a change in the form of time which is appropriate. Of course, the change itself requires 'time' (in yet another sense) to be carried out.

Orders of agility

The idea of orders of change (Figure 2(b)) can now be generalised in an expression of *orders of agility*. This recognises differences in kind in the different forms of agility, which have been

identified within the CIBM C2 agility work, the first phase of which was a thorough literature review[3] covering the academic, military and commercial uses of the term *agility*.

A simple example of orders of agility is presented by the distinctions evident in the work of the SAS-085 working group [5] between:

- C2 approach agility - the degree of movement attainable, in terms of coverage of the operational challenge space, within any particular C2 Approach (for example, de-conflicted, coordinated, collaborative);
- C2 agility - the ability to move between different C2 Approaches (assumes sensing capability and cognitive capability to recognize need to move and then how 'best to move') [6] [7].

We would describe C2 agility, as defined here, as being *of higher order* than C2 approach agility. Table 1 identifies four orders of agility, shown as columns. The entries in Table 1 in the different rows include the various dimensions of agility developed above in relation to forms of time, along with some additional entries, drawn from the broader work on C2 agility:

- *qualities* (i.e. 'ilities') relate to the attributes or *dimensions* of agility identified by the SAS-085 group [5];
- *change and continuity* refers back to the earlier paper [1], which noted the ever-present interplay between continuity (i.e. preservation of identity and forms of order) and change, and the need to understand the model of change through which agility is exhibited.

Looking at the broader agility literature, it is possible to see where authors have picked on particular orders of agility as being truly characteristic of agility. For example, Kidd [8] describes agility as:

> "*a strategic response, not tactical, and involves building defense against primary competitive forces through co-operation….a holistic concept….a paradigm shift, where processes, structures, organization, people, implementation capabilities, etc., are the main issues*".

Such second-order and third-order characteristics, as an exhibition of agility relating to flow of movement and openness to change of direction, etc., should be contrasted with the more recently-emerging understanding of agility in terms of addressing firmly-stated customer requirements within the modern competitive environment. Here the dominant characteristics appear to be efficiency, performance, leanness and responsiveness to changing levels of demand [9], which all point to first-order characteristics.

The contrast lies between the process-performance concepts of doing business in an agile manner (i.e. physically lean to perform efficient actions and to deliver a speedy response) and being capable and configurable to be agile (i.e. being open and able to sense and effect change). Van Hoek et al [10] express it thus:

> *Agility is all about creating that responsiveness and mastering the uncertainty. In that respect the agile mindset is at variance with the lean production model that is commonly embraced in supply chain management."*

Thus, orders of agility give us a framework within which interactions between these (and other) competing perceptions of agility can be understood and then used in C2 research and practice.

[3] This is a set of three unpublished working papers that can be requested via the point of contact for this paper.

Dimensions	Zeroeth order	First order	Second order	Third order
Orders of agility in respect of entries in Figure 1				
React, anticipate, shape	• React (but no change)	• React (within extant model of change)	• Anticipate	• Shape
Locus of decision-making	• (No decision required)	• (No decision required)	• Escalate • Devolve • Change the conditions on escalation / delegation	• Change the topology of command • Change the principles of command and delegation
Knowledge type	• *Techne* • *Episteme*	• *Episteme* • *Phronesis*	• *Phronesis* • *Metis*	• *Phronesis* • *Metis*
Understanding, formulation and conceptualisation	• Observe and report • Feedback-based control	• Registration of comfort / discomfort • Appreciation, identification of choosable Ways, evaluation, commitment • Classification • Application of narrative	• Vantage point analysis of focus / frame evaluation • Re-framing • Modify the basis for classification • Modify the narrative • Change appreciation of utility of Means • Change the locus and bounds of choosable Ways	• Change the way in which the environment is appreciated • Change the narrative landscape
Forms of time	• *intentional*	• *intentional* or *successive*	• *intentional* and *successive* components & interplay	• *successive*
Orders of agility for other aspects of agility				
Qualities (i.e. 'ilities')	• Resilience; tolerances and adjustability	• Associated with adaptation: flexibility, innovation, availability, versatility, responsiveness		• Associated with transformation
Change and continuity	• Continuity (no change)	• Change, using extant model of change	• Adjustments to model of change employed (e.g. within regulatory framework for market / ecology)	• Change to a completely different model of change

Table 1: Orders of agility

Interpreting and using orders of agility

Orders of agility, as set out in Table 1, offer numerous insights. One of many patterns visible in Table 1 is made explicit in Figure 3, which develops the theme of continuity and change with which this paper opened.

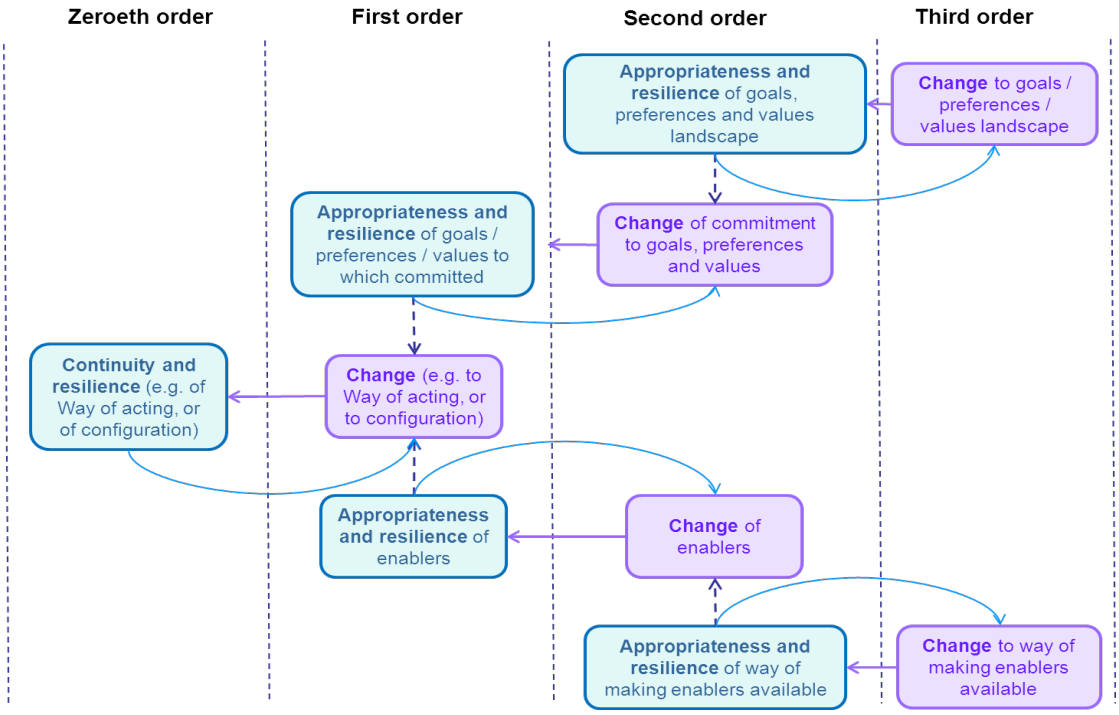

Figure 3: Continuity, resilience and change shown against orders of agility

Similarly, it is possible to infer from Table 1 the recourse to increasingly 'smart' responses (to real or potential challenges) open to intelligent commanders through having access to higher-order agility (both capacity and capability), when faced with poor outcomes or behaviours exhibited by lower-order responses (for example, errant behaviours relating to organizational disturbance, diffusion or rigidity).

THE CREATION, TASKING, CONFIGURATION, EXECUTION AND REPORTING OF *DECISION SYSTEMS*

This discussion leads naturally to a desire to unify our understanding of orders of agility with our understanding of decision-making. Command and control is about people making decisions according to whatever choices might be available to them at the time of decision. Choices are options relating to focus of attention, interpretations of a situation, and courses of action, adaptation and/or transformation.

Theories based around a focus on people's freedoms or remits for choice are central to C2 agility. One such theory of choice [11] can provide conceptual support when there is both a complex social mix and a challenging degree of open-endedness, uncertainty, ambiguity, confusion, volatility, contention and unknowns in the situations being faced. Such theories can provide insight and support reasoning about the challenges brought about by differences in ways of sensing, observing, noticing, interpreting, modelling, sense-making, deciding, assessing, adapting and acting in our increasingly open, contentious and complex world.

In this paper, the concern is not with discrimination *between* options, but rather with where choices come from (i.e. *choice-ma*king, and the ways in which choice options and freedoms for choice can be negotiated). A simple approach here might be to portray decision-making as the traversal and execution of graphs instantiating the pattern shown in Figure 3, searching for satisfaction at the lower orders of agility and, if not found, then standing back to re-visit the higher-order decisions that change the choice conditions (goals, preferences, values, enablers) which define the wider problem-space. In practice, this account has to be taken apart and examined more forensically, taking greater care (for example) to distinguish between decision-*making* and decision-*taking*; also adding *choice-making* or *shaping*. This leads to a decision-based architecture, which can be more fully reconciled with the notion of orders of agility.

One possible characterization of decision-taking is as the pursuit of a solution within a declared space of possibilities which is bounded by constraints and enablers[4]. The results of applying the principle of orders to decision-taking are shown iconically in Figure 4, where we have characterised the space of possibilities as a cube[5].

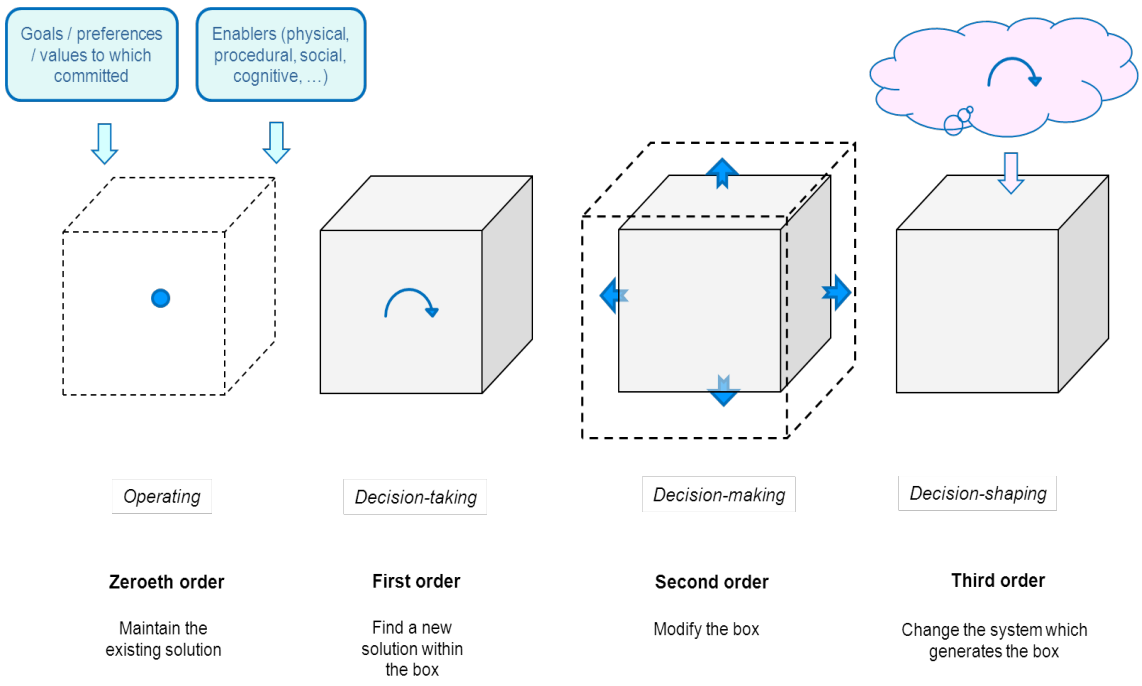

Figure 4: Application of the principle of orders to decision-making and decision-taking

The zeroeth-to-third orders in Figure 4 have been labelled, respectively, as:

- *operating*: choosing to take response (re)actions to sustain and maintain operative functions;
- *decision-taking*: selecting courses of action to achieve operational outcome;

[4] This reflects a model of planning as design, which corresponds to the use of a *computational* lens; as will be discussed later, this is not the only possible model of planning.

[5] So the cube always represents both the computational problem to be solved (e.g. allocation of physical resources to the meeting of an operational objective) and the capacities (physical, procedural, social, cognitive, etc.) which are made available to the decision process.

- *decision-making*: organizing to restrain, enable and empower the decision-taking, through for example delegating decision rights, setting up depths of supervision on behalf of others, tightening or loosening tolerances and freedoms of action;
- *shaping*: setting and re-setting policy and boundary conditions, veto arrangements and building relationships to shape the operational context.

A model of the making and taking of decisions

In order to illustrate the relationships between operating, decision-taking, decision-making and shaping, it is useful to consider a two-level model in which the taking of decisions at one order is contextualised by higher-order decisions defining the decision-space (or problem-space). This is presented in Figure 5; note that the construction of this diagram is described in more incremental and discursive terms in Appendix A.

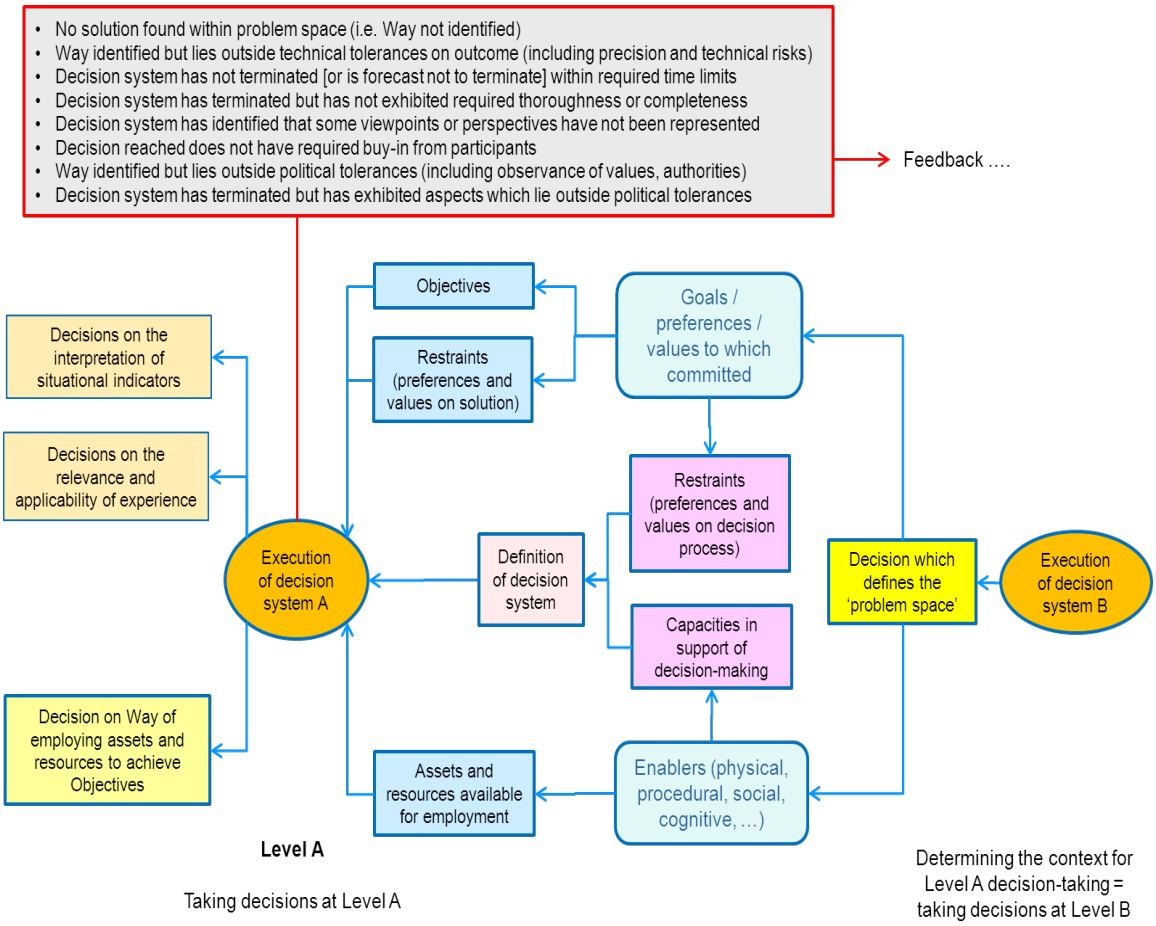

Figure 5: A model of the making and taking of decisions

In this figure, the 'problem space' (as represented by the cubes in Figure 4) is defined or constructed at Level B, and decisions within that space are made at Level A. The feedback messages essentially represent requests for re-formulation which amount to second-order agility (or higher). In other words, having not found solutions at the lower orders of agility, requests are made to re-visit and revise, higher-order decisions. Higher-order decisions may be taken to:

- change the decision system, e.g. the way in decisions are intended to be reached at Level A;
- change people's preferences and evaluation criteria. which are pertinent to the Ways of employing assets and resources to achieve Objectives;
- change the understanding, formulation and conceptualisation of the situation, via changes in the reference frames being employed at Level A.

In the longer discussion of this diagram in Appendix A, the point is made that differences of order cannot be related directly to the levels of the command hierarchy. We must resist the easy identification of the movement from left to right in Figure 5 (i.e. from zeroeth to third order) with the command hierarchy (i.e. subordinates to the left, superiors to the right).

The exercise of agility through interaction between orders

We can say in summary that agility can be exercised, at the four different orders introduced previously, through *activities.* These activities encompass:

- *instruction* – tasking, allocation, communication of constraint, restraint, preference or value;
- *application* - exercise of an instruction, constraint, restraint, preference or value;
- *violation* - of an application;
- *reporting* - of a successful application, or of a violation;
- *requesting* - of a suspension or modification;
- *suspension* - taking a local decision to rescind or not to apply an instruction;
- *creation* – of a new tasking, allocation or constraint;
- *modification* - effecting a change in an extant item which may then form the basis for an instruction.

Figure 6 shows the activities in relation to two adjacent orders, at each of which decisions are taken and the results communicated to the other order. Again, the figure can be applied recursively to span our orders zero-to-three.

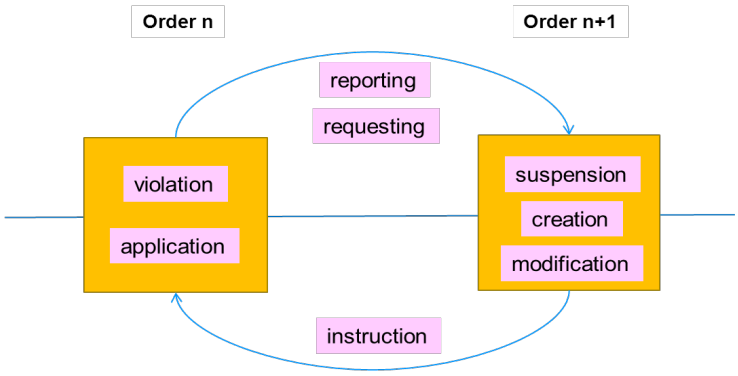

Figure 6 Activities shown on a simple two-order model

The instructions being passed from the higher to the lower order may constitute either enablers or inhibitors of agility. In other words, the higher orders of agility may be pointing to constraints, restraints, preferences and values which, if not addressed, are the key inhibitors of agility at lower levels[6]. Change can be blocked, as well as enabled, by the higher-order activities.

Although Figure 6 portrays a message-passing system, we need to remember that the two blocks in the figure (labelled 'Order n' and 'Order n+1') are a*bstract* or *virtual* 'nodes': they *may* be distinct in physical and/or structural terms, but they could equally well be referring to sets of activities taking place within the mind of a single individual.

Understanding organizational activities in relation to agility in decision-making

Figure 5 showed objectives, enablers, constraints and definitions (e.g. prescriptions) impacting on the execution of the decision system A. The activities of Figure 6 provide us with one way of abstracting what is happening, but we need also to attend to a second dimension which pertains more to the socio-technical form of the C2 organization.

An unduly mechanical interpretation of Figure 6 (e.g. as a set of 'information flows') conceals the fact that the activities and interactions in Figure 5 exhibit differences in kind. For instance, preferences (such as aversion to particular types of risk) may be established and communicated through cultural systems (of training, education, relationships with superiors) which are quite separate from the administrative dimension of formal orders and allocation of assets and resources. We may speak of multiple 'media' or 'organizational systems' (which we could denote as 'o-systems') through which activities and interactions are played out. Thus we have already mentioned:

- an o-system through which formal tasking of subordinates and staff is achieved;
- an o-system through which personnel (both military and non-military) are allocated to decision systems – this will have both administrative and social dimensions;
- an o-system through which preferences and risk appetites are promulgated – this will have both doctrinal and political dimensions.

These examples point us towards a general model of agility in decision-making: agility can be exercised, at different orders, through different o-*systems*. These o-systems are inter-penetrating, in that they are all present at all points in the C2 organization, although each may also extend into the wider world in different directions. Each o-system also constitutes a channel for communication and adaptation, and of course each o-system has its own forms of time and its own models of change. 'Agile decisioning' means taking decisions to pursue efforts (or invoke actions) in respect of particular orders in relation to particular o-systems or (more commonly) combinations of o-systems.

This has now opened up a second dimension to our message-passing visualisation, in that we now have 'messages' being sent between o-systems (as well as between orders).

- Thus (for example) a commander may be aware of a possibility of a novel course of action, and may have the assets to enable it, but it will not happen if he does not also have the *will* to commit to it – and this will may be inhibited by a 'risk aversion' signal

[6] Such changes can be capable of trumping the presence of other enablers and valencies (for example, the intellectual capacity of the commander to exercise 'first-order' creativity in coming up with novel courses of action).

coming from some kind of doctrinal and political o-system. The following distillation of practitioner views was generated earlier[7] in the CIBM research work on C2 agility [12]:

> "When any military person understands doctrine and his Commanders' Intent (note plural), including devolvement of responsibility and authority, then he is empowered to act with agility. His mind-set and his training help to determine whether or not he will act with agility. When thinking or acting in an agile fashion, he will tend to be willing to take assessed risks. A risk-averse (and therefore non-agile) mind-set can often be tracked back to lack of trust between him and his superiors, subordinates or colleagues. Whether or not he can act with agility sometimes depends on the availability or absence of communications and on having the correct level and/or coherent display of relevant information."

Whilst the availability of Means and the intellectual capacity to identify a Way of employing these Means could be characterised as enablers of first-order agility, the engendering of Will (through a culture of empowerment, as opposed to risk aversion) seems to point to higher orders of agility. Means, Ways and Will analysis is often used as a triplet to inform trade-offs. We can now see this as being an interaction between different o-systems.

From o-systems to lenses

Although the idea of o-systems is interesting, we are hostages to fortune if we attempt to enumerate them. However we can side-step this problem if we think not just about the o-systems themselves but about the ways in which the different o-systems might exhibit properties and might be observed or described. This does nothing for our appreciation of organizational ontology, but it does at least give us a classification of appearances.

For this purpose we can employ a set of *lenses* which have evolved within the CIBM Research Programme. Lenses are *ways of viewing* organizational activity, and have now been employed in a series of Research tasks, and so offer a reasonably mature set. Twelve lenses have been identified:

- administrative;
- functional;
- computational;
- procedural;
- communicational;
- socio-structural;
- physical;
- judgemental;
- macrocognitive;
- adaptational and transformational;
- representational;
- anthropological.

[7] This account [12] was written before our abstract models of C2 agility were developed, but its anticipation of the ideas in the current paper should be evident.

A definition is offered for each of these lenses in Appendix B, which also relates each to one or more founding metaphors based (for the most part) on the work of Morgan [13].

A general model of agility in decision-making

If we move from o-systems to lenses, we can say that agility can be exercised, at different orders, through activities which can be viewed through different lenses. Since the activity set (Figure 6) is independent of the lenses, this agile activity can be portrayed as occurring on a two-dimensional grid (order x lenses), as shown in Figure 7.

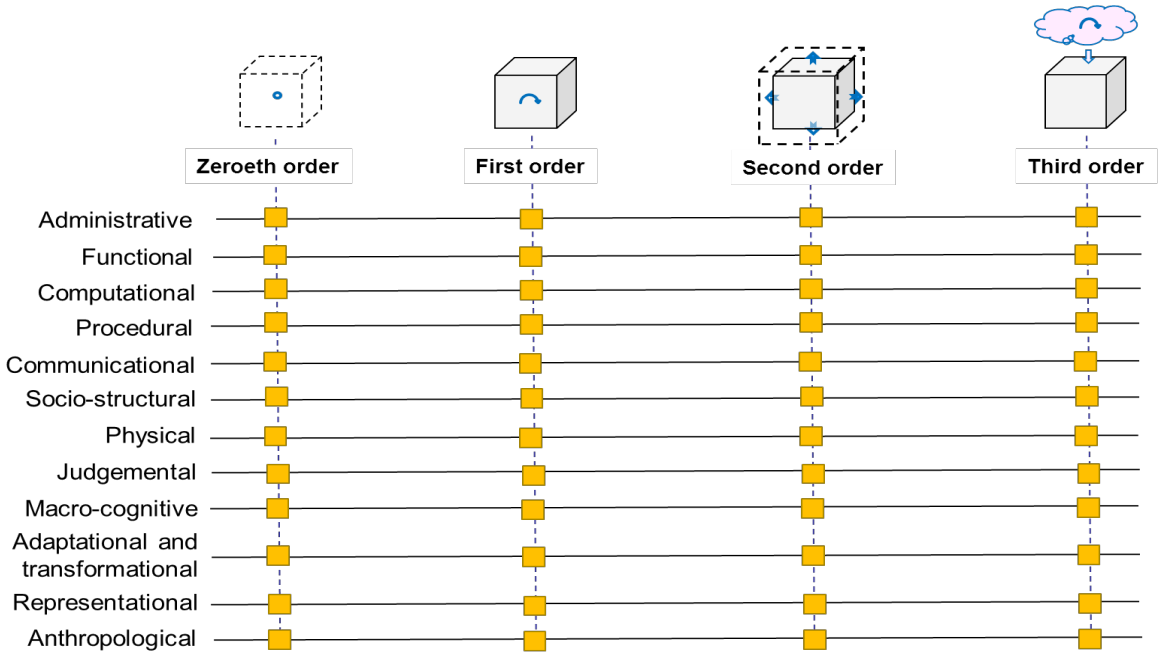

Figure 7: Grid on which agility options can be exercised

Again we must reinforce the fact that the 'nodes' in Figure 7 are purely abstract: this is an *interpretation model*, which is being applied to the whole of the C2 organization but which could also, in the limit, be applied to the activities of a single individual. So the 'messages' being sent (both horizontally and vertically) may not be (and in generally will not be) exhibited directly as physical messages.

Note that decisions can be exhibited in relation to any of the 48 nodes shown in Figure 7, and indeed it may not be possible to localise a particular decision to a single node, but rather to groups of nodes which are implicated. Note that the classical view of "the decision made by the commander", as the 'operational-decision-taker-in-chief' (i.e. the selector of the Course of Action from the alternatives presented) focusses on just *one* of these nodes (the first-order computational entry). Thus should appreciation of organizational decision-making be expanded.

In the earlier Table 1, we showed a number of facets of agility organized against the dimension of orders of agility. We can now update that table (to create the new Table 2) by showing the same items (and some additional entries) organized in terms of the two dimensions of the grid in Figure 7.

Dimensions	Zeroeth order	First order	Second order	Third order
Administrative	Fixed objectives	Fixed objectives	Change the objectives and the policies applied Change the Means made available	Change the operations landscape Change the way in which Means are made available
Functional			Change the way in which specific dependencies are fulfilled	Changes the way in which dependencies are created and fulfilled generally
Computational	Fixed objectives Feedback-based control	Fixed objectives Feedback-based control Appreciation, identification of choosable Ways, evaluation, commitment	Change the objectives, constraints and tolerances Change the Means made available	Change the operations landscape Change the way in which Means are made available
Socio-structural		Exercise of the different perspectives represented	Include or exclude representatives of different functional / organizational / cultural perspectives	Change terms of participation in operation by representatives with different organizational / cultural affiliations
Macro-cognitive		Application of classification Application of narrative Appreciation, identification of choosable Ways, evaluation, commitment	Vantage point analysis of focus / frame evaluation Re-framing Modify the basis for classification Modify the narrative	Change the ontological landscape Change the narrative landscape
Adaptational and transformational		Feedback-based control Registration of comfort / discomfort Appreciation, identification of choosable Ways, evaluation, commitment	Re-framing Modify the basis for classification Modify the narrative	Change the ontological landscape Change the narrative landscape Change the way in which Means are made available
Representational		Application of classification	Change the Means which are employed Modify the classification	Change the ontological landscape
Anthropological		Empowerment Registration of comfort / discomfort Application of narrative	Change the commitment to or application of preferences and values Modify narrative Suppress or promote diifferent organizational/ cultural perspectives Change the Means which are employed	Change the preferences / values landscape Change the narrative landscape Change the way in which Means are made available

Table 2: Illustrative entries for the different lenses in respect of orders of agility

Note that Table 2 makes use of eight of the twelve lenses[8].

Relationships between nodes on the grid

In relation to the earlier one-dimensional figure (Figure 6), we interpreted the instructions being passed from the higher to the lower order as either enablers or inhibitors of agility.

This understanding now needs to be extended to the two dimensions of the grid (Figure 7), by dealing with the 'vertical' relationships between the activities as observed using the different lenses. This richness provides alternative, relational ways of viewing any organization, although particular metaphors (and hence particular lenses) may prove more or less compelling in specific circumstances.

Again we are concerned with the flow of:

- *enablement* or *inhibition* (the vertical equivalent of the earlier *instruction*);
- expressions of *comfort* or *discomfort* (i.e. including signals of success or failure - the vertical equivalent of the earlier *reporting* and *requesting*)

A working organization has to operate effectively through all of its o-systems, as viewed through all of the available lenses. Thus for example, an inhibition or disabler visible in one lens affects the organization as a whole: we cannot bypass the blockage simply by focussing on lenses which portray an 'unblocked' picture.

Losada [14] takes a psychological view of what might limit or *afford* agility and flow in individuals and organizations. So, for example, he looks to connectivity as providing the measure of a relationship's 'generativity' (i.e. ability to generate agility) and openness to new ideas and influences and ability to deflect behaviours that will shut down 'good' generative processes. Connectivity is made up of three 'balances' being made between:

- inquiry and advocacy;
- external and internal focus;
- positivity and negativity.

Losada's work has been used to study high performing teams (i.e. those that have the capability and are being supported organizationally in order to do and give of their best). He takes a complex adaptive systems view of team behaviours, seeing them as emergent behaviours. So he talks about the ability of a team to dissolve attractors that close possibilities and to evolve attractors that open possibilities for effective action. So, in his language, high performing teams are high in both inquiry and advocacy, they do not get locked down with negativity, advocacy or self[9]. They are

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[8] The remaining four lenses are procedural, communicational, physical and judgemental. The first three of these are perhaps more implementational rather than conceptual in their flavour, and hence less suited to what is (at this stage) a conceptual analysis. In respect of the judgemental lens, it would be very interesting to consider the facets (e.g. biases) which might come into operation within our scheme, but this is well beyond the scope of the current paper.

[9] The "Losada Line" separates people who are able to reach a complex understanding of others from those who do not. People who "flourish" are above the Losada Line, and those who "languish" are below it. The Losada Line bisects the type of dynamics that are possible for an interactive human system. Below it, we find limiting dynamics represented by fixed-point attractors; at or above it, we find innovative dynamics represented by complex order attractors.

able to dissolve these attractors, consciously or unconsciously carrying out meta-learning, double-loop learning or something at an even higher degree of adaptation – all of which we now express as a recourse to higher orders of agility.

INFORMATION: ENABLING AND INFLUENCING DECISION MAKING

We have repeatedly referred to the idea of 'message-passing' between the nodes on the grid, albeit with the caveats that the nodes are abstract and the 'messages' will in general not be exhibited directly as physical messages. It is pertinent to consider how these messages (both horizontal and vertical) be correlated with our understanding of information and, in particular, the capacity to enable and influence decision-making.

In Appendix C, we show how these issues relate to strands in the broader literature on information, understood as that which makes a difference to the way we think about things or to our disposition to act [15]. The observation that there are forms of information which may need to be received 'just to stand still' (rather than to induce any change in 'information position') conflicts with the more commonly-held view (e.g. [16]) that information is a message meant to change the receiver's perception. The upshot is the rejection of 'mechanical' or 'computational' treatments of information and its impact on decision-making.

Consideration of the 'vertical' messaging on the grid (e.g. the cross-inhibition of activity in one lens-line by another), finding some general expression of the rules of an information system addressing multiple lenses appears challenging. This lead to the conclusion that the framework through which information is assigned both meaning and value is dependent on the model or pattern of the 'decision-work' which is being followed.

This understanding of information would undoubtedly be helped by the pursuit of a parallel analysis (to the one offered in this paper) which considers *sensemaking* rather than decision-making. One of the points of departure could be the reference to $\Delta\theta_{max}$ in Figure 2(b), denoting a shift of emphasis between observing, interpreting and taking action. Also of interest here would be the idea of weak signals, alertness to which is, for Holsapple and Xi [17], a hallmark of organizational agility.

CONCLUSIONS

The paper has built on and reinforced the conclusions from the earlier paper [1]:

- A rich understanding of agility cannot then be related to a single form of time derived from classical mechanics.
- There are some important concepts of C2 agility – particularly those associated with mental agility – which can only be understood in relation to forms of time other than the *chronos* of sequential, clock-tick time or, equivalently, Jaques' intentional and forward-projected dimension of time [4].
- There is a need to employ organizational metaphors [13] other than that of the machine in order to understand the organizational complexes from which C2 agility emerges. Use of different metaphors (e.g. brain, culture, organism) provides us with the stimulus to see the various forms of time being exercised in both the C2 organization and the environment in which it is operating.

The earlier recognition of different forms of time at work in relation to C2 agility can be broadened to recognise different *orders of agility*. Different exhibitions of agility

(involving the physical, computational, cognitive, social and political facets of the C2 organization) can now be related to different orders of agility.

We have considered the application of orders of agility to decision-making, where our primary concern is not with discriminating between options, but rather with where choices come from (i.e. *choice-making*, and the ways in which choice options and freedoms for choice can be negotiated). We have developed a model of interacting decision systems whose behaviour can be interpreted using orders of agility (and indeed different forms of time). We have noted the fallacy of seeking to correlate directly the orders of agility with the levels in the command hierarchy. It is more appropriate and useful to relate the orders of agility with the degree and form of time defining the feedback. For example, third-order changes may not be discernible in terms of observable outcomes; they may need to be *felt* in terms of changes in nature of opportunity, which may also take many cycles of change to be realised.

Decision systems are organizational constructs, and hence their behaviour needs to be viewed and expressed using multiple dimensions which we associate with the use of different *lenses* (i.e. different ways of viewing organizations). This has given rise to a model of organizational decision making taking place on a two-dimensional grid formed from the orders of agility and the lenses, with various forms of message-passing taking place between the nodes of the grid and acting to inhibit or enable the different forms of exercise of agility.

This grid is an interpretation model, rather than a specific reference to ontological components within the C2 organization. So the 'messages' being sent will, in generally, not be exhibited directly as physical messages. This has led naturally to a reconsideration of *information*, understood as that which makes a difference to the way we think about things or to our disposition to act [15].

The outcome is a rejection of 'mechanical' or 'computational' treatments of information and its impact on decision-making. Furthermore, we have shown that it is not possible to assign a value to information without access to the dominant model(s) of 'decision-work' in use within the decision systems.

Acknowledgement

Our understanding of Morgan's metaphors and the use of lenses in organizational studies derives from many discussions with colleagues within the CIBM Research programme and forerunner studies. Particular thanks are due to Mark Round for the codification and description of lenses used in this paper.

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APPENDIX A: A MODEL OF THE MAKING AND TAKING OF DECISIONS

In this Appendix, we present a more incremental and discursive account of the thinking leading to the model of the making and taking decisions presented in Figure 5. We also consider the extent to which the orders of agility can be correlated with the levels of the command hierarchy:

- In Table 1 we identified escalation of decision-taking as an illustration of second-order decision-making.
- It is also very easy to characterise operating, decision-taking, etc. as a set of roles played at various levels in a command hierarchy (e.g. thinking of shapers as operating primarily at higher levels in a command hierarchy, such as coalition commanders). Indications like this might lead us to conclude that the movement from left to right in Figure 4 (i.e. from zeroeth to third order) might be describing the workings of the command hierarchy (i.e. subordinates to the left, superiors to the right).
- We need to resist this easy identification, and the demonstration of why this is so should prove instructive.

We start by considering a simple model of decision-making and decision-taking that might have led us naturally to the command levels interpretation. In Figure 8 the 'problem space' (as represented by the cubes in Figure 4) is defined or constructed at Level B, and decisions within that space are made at Level A. The feedback messages essentially represent requests for re-formulation which amount to second-order agility (or higher). In other words, having not found solutions at the lower orders of agility, requests are made to re-visit and revise, higher-order decisions.

Note that moving from left to right in Figure 8 is, as with Figure 4, a move to a higher order. Although this is only a two-level model, it can be applied recursively (so decision process B is in turn executing decisions whose context has been set at a yet higher-level).

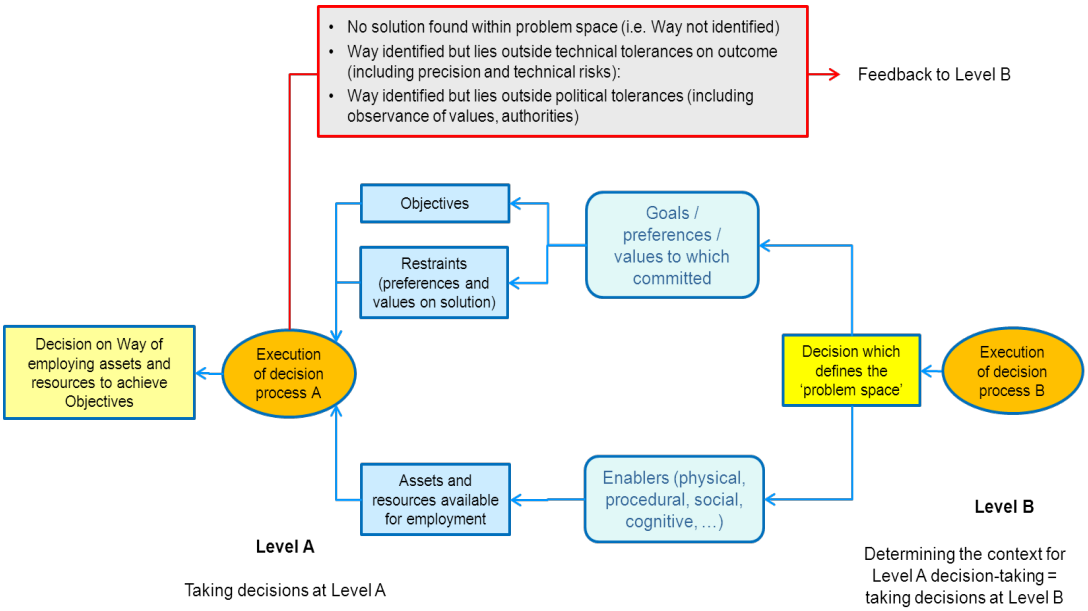

Figure 8: A simple model of the making and taking of decisions

Thus far, it may be tempting to equate Level B with the role of a superior commander. But missing entirely from the discussion so far is the *decision process*. The decision process may itself have constraints and enablers, meaning (for example) that pursuing an exhaustive search of the space of possibilities is unrealistic. Hence, a decision procedure such as Recognition-Primed [18] may be advocated, placing a high value on the ability to relate a problem or a proposed solution to previous cases.

Returning to Figure 4, recalling that the cubes are a representation of both the computational problem to be solved and the capacities being made available to the decision process, then we should be speaking here of a *decision system*, which will reflect all of the dimensions of organizational behaviour (process, structure, participation, knowledge, etc.).

Decision systems are created with a view to more than just computational challenges. In previous work, we have considered how decision systems can be created under conditions of high social diversity (i.e. representatives of multiple organizations). Decision systems will be collaborations in the sense of structures in which diverse participants, with a common purpose or an overlapping set of purposes. There are circumstances in which this diversity is so great that consensual decision-making is not a viable option and yet competing views still need to be voiced and heard.

Organizational patterns such as 'Breathing in, Breathing out', 'Generalised Future Scenarios' and 'Re-connecting with Reality' [19] are choices for decision system architectures which seek to resolve competing tensions in effective organizational design; for example, the inherent tensions in:

- the dangers of mindset / groupthink (i.e. premature framing) *versus* lack of a compelling narrative (multiple and competing frames);
- the desire to maintaining momentum (with the risk of ignoring reality) *versus* the desire to attend to changes in the environment (with the risk of 'over-fitting the data' or hypersensitivity).

In view of the fact that there is no *universal* way of resolving such tensions, the only option is to adopt pragmatic decisions about the organizational patterns to be pursued in the context of particular situations. This makes it clear that the commander has two roles:

- Campaign / Operation / Mission Management, in which the Commander is 'looking outwards' to the operating environment and actually managing the progress of the campaign (or operation, or mission) itself;
- Command Management, in which he sets in place (and monitors the effectiveness of) the internal arrangements of his own organization – which clearly includes defining the decision system.

Indeed, notwithstanding his continuing role as 'operational-decision-taker-in-chief', determining the shape of the decision system may represent the most important decisions which the commander can take. It will in fact do much to determine whether his HQ is capable of exhibiting C2 agility.

Thus, Figure 8 needs modification to add a step to the determination of the decision system, and add new forms of feedback granularity pertaining to how well the decision system is working, resulting in the model depicted in Figure 9 (which reproduces Figure 5 in the main body of the paper).

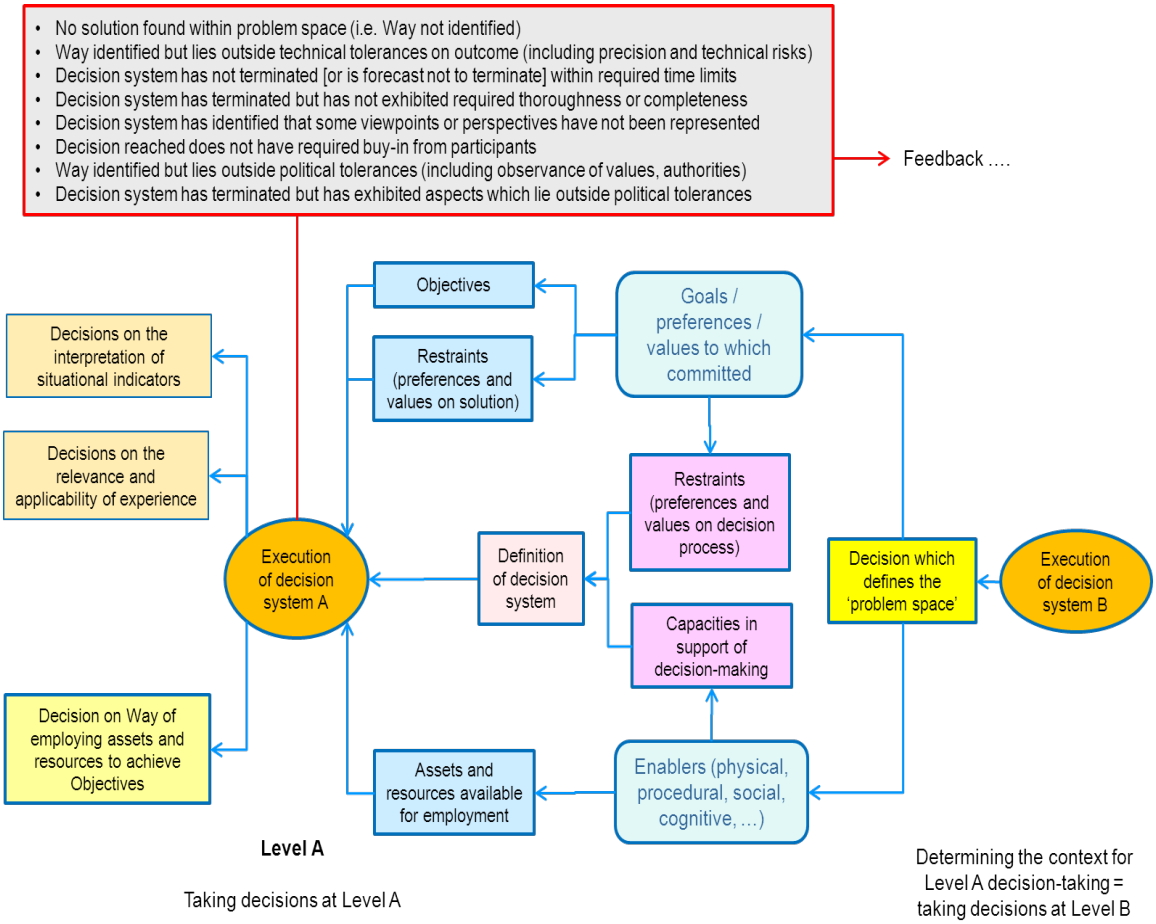

Figure 9: A refined model of the making and taking of decisions

It should now be obvious that, in general, the possible responses to this feedback cannot be associated with a single role. If we assert that the decision-taking level denoted Level B represents the superior commander, we cannot simultaneously assert that Level B is invariably where the following changes are effected.

- <u>Changes to the decision system</u>.

  The decision system may well be defined at Level A (rather than at Level B), working with the available capacities and in respect of extant preferences and values. So some feedback on the workings of the decision system could well be addressable internally within the Level A organization.

  On the other hand, there are preferences being declared, not only on decision-outcomes but also on the way in which those decisions are reached. These preferences may reside in a broader system (with social and political content), which may extend well beyond the military organization and yet they all have to mesh to generate coherent activity (as Clausewitz's "war is policy").

For example, Figure 9 identifies one possible form of feedback as "Decision reached does not have required buy-in from participants"[10]. In the context of inter-organizational involvement in the planning, this would be tantamount to a decision-system failure condition, even if the solution emerging was technically or objectively satisfactory. The term "required buy-in" refers to a preference for, or value placed upon, the willingness of partners to endorse solutions.

When preferences are violated, solutions are more akin to resolutions and so could include:

- going ahead with the decision anyway;
- the local relaxation or finessing of that preference (a second-order approach); or,
- the re-shaping of the preferences landscape (a third-order approach) – in our specific example, re-shaping such that the general expectation of partner endorsement is relaxed.

Neither of these may lie within the remit, authority or capability of the superior commander who created the original tasking.

- Changes to people's preferences and evaluation criteria. which are pertinent to the Ways of employing assets and resources to achieve Objectives.

  Preferences and values include risk profiles and authority / responsibility guidelines. A commander at any level may be willing to suspend or finesse these locally, but such actions (and indeed the making of more fundamental shifts in expectations) belong to a political system within the organization which cannot be equated to the formal command hierarchy.

- Changes to the understanding, formulation and conceptualisation of the situation via changes in the reference frames or viewing lens.

  Symptoms of this are the way in which situational indicators are interpreted, and the way in which relevance and applicability of experience are assessed (e.g. is this a situation we have met before?).

  Classification schemes and narratives may have been assumed or even re-stated by a superior 'Level B' commander, but refinement and evolution of these take place within a broader system which will have social, political and doctrinal facets. Nor can we assume that superior (or even strategic) commanders have a monopoly in this area: tactical commanders, non-military partners, local social entities and even the media may play key roles in changing the narrative. A good commander should, of course, recognise and exploit this, but we cannot express the capacity to achieve this in terms of the formal command hierarchy of a military organization, even though this is a key aspect of civil-military coordination regularly discussed in the C2 community.

[10] Implying that diverse views have been brought to the table but the decision system has not succeeded in generating a solution with which the various parties present are sufficiently happy.

APPENDIX B: DEFINITION OF THE LENSES

Table 3 describes the meaning of each of the lenses, and also relates each to one or more founding metaphors based (for the most part) on the work of Morgan [13].

Lens	Founding metaphors	What it describes
Administrative	Machine, political system	How the work of the C2 organization is managed (tasked, approved); also how administration within the operation is planned
Functional	Machine, organism	The purposes met by the decision system; the requirements it places on other parts of the C2 organization (including other functions such as Intelligence); how it contributes to the delivery of superior functions; other functional interdependencies
Computational	Machine, organism, brain	An abstract account of the 'operational problem' posed to the decision system; ideally expressed in terms of universal constraints
Procedural	Machine	How work 'triggers' work; how these workflows are formalised
Communicational	Machine, network	How information flows through, into and out of the decision system
Socio-structural	Machine, political system, instruments of domination	How the work of the decision system is organized, within a HQ and between actors
Physical	Machine, brain, culture, instruments of domination	How the work of the decision system is embedded and organized in physical space, and around physical objects (e.g. bird-tables)
Judgemental	Brain, political system	The deviations from 'good' decision-making that occur, and the factors that make them more or less likely
Macrocognitive	Brain, political system, culture	The bases of expert performance in individuals and teams participating in decision systems; addressing cognitive processes, heuristics, meanings…
Adaptational and transformational	Organism, flux and transformation	How aspects of decision systems are adapted, and how their participants learn, in response to the situation;
Representational	Machine, culture	The explicit models of representation (e.g. plans, orders) that decision systems employ
Anthropological	Brain, political system, culture, psychic prison, instrument of domination	Political, moral, ethical and legal considerations that bear on decision systems; also culturally-specific practices (e.g. rituals). How the decision systems create a script for the work to 'control the narrative' in-theatre, and for interpreting success or failure

Table 3: Lenses employed in the description of the C2 organization

APPENDIX C: INFORMATION: ENABLING AND INFLUENCING DECISION-MAKING

We have repeatedly referred to the idea of 'message-passing' between the nodes on the grid, albeit with the caveats that the nodes are abstract and the 'messages' will in general not be exhibited directly as physical messages. So to what extent can these messages (both horizontal and vertical) be correlated with our understanding of information and, in particular, the capacity to enable and influence decision-making?

In his review of different definitions of information, Houghton [20] identifies that many definitions of information focus on the correspondence between information and the state of the world. [20] seeks to distinguish between:

- observable aspects of the external world
    - i.e. 'external to the information system' - this could refer to a number of different domains which are physical, social, cognitive or virtual in character;
- representations (e.g. in symbolic form);
- the consequences of attention-setting (embedded assumptions or active decisions about which observable aspects are worthy of representation, transmission and perception);
- the assignment of meaning (i.e. the interpretation of symbols and signs in a purposive context;
- the assignment of value (i.e. the capacity to change the way that people think and their disposition to act).

In the present paper, we are concerned solely with information *value* and the *nature of the referents* to which information (in support of decision-making) relates[11].

Clearly these referents will pertain to both the C2 organization (in its physical, social and cognitive domains, viewable through the twelve lenses) and the environment in which the organization is living. In both [21] and the continuing CIBM research[14], we have emphasised that there is significant human and organizational content in the information employed in support of decision-making, wherever we are dealing with situational and organizational complexity. Working with partners (e.g. non-military) within the collaborations on which decision systems are based, we must have knowledge not only of the 'external conflict situation'[12] but also of ourselves and each other. For example, how do our different cultures, norms and practices impact upon our ability to generate 'cognitive alignment'? How might personal, organizational and societal history of education, learning and experience also affect such alignments?

In our new language, we can assert that the information 'about ourselves' must reflect all of the o-systems (administrative, social, political, doctrinal, etc.). Given our unwillingness to enumerate these o-systems, the best we can say is that there are distinctive forms or appearances of information in respect of each of the lenses (administrative, computational, socio-structural, etc.). Specifically, there are forms of information flowing along the lens-lines between the nodes in Figure 7.

Turning to information value, we are seeking to understand how to express the capacity of our 'messages' to change the way that people think and their disposition

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[11] In contrast, in an earlier paper [21], we were concerned primarily with *meaning* (how it is constructed, how it is conveyed and shared, and how it can be lost through loss of context).

[12] The quotation marks reminding us that (a) the notion of an objective external world may be fallacious and (b) we may not have access to it anyway – we know only what our own sensors and sources are telling us.

to act. Shannon [22] regards information as something that modifies our knowledge or beliefs[13] about the world. Houghton [20] attributes to Boisot [15] the insight that information acts upon our probability distributions and modifies them, in other words that *information makes a difference to the way we think about things or to our disposition to act*. The reference to 'probability distributions' surely anchors the idea to a computational view on decision-making. Our newly-gained awareness of the other lenses should encourage us to think of other forms of 'knowledge-state' (e.g. appreciation of societal norms) and other ways of acting upon such states.

The nature and impact of information is expanded in the position taken within the CIBM Research Programme on inter-organizational shared situational appreciation (SSApp)[14]. Here, information is that which contributes to the cognitive alignment necessary to enable participants in a collaboration to achieve coherent decision making. Clearly this includes knowledge of our partners as well as some external world, and again we cannot expect to be modelling organizational belief systems using probability distributions.

Note that Boisot [15] does not commit to saying that the arrival of information *will* make us act differently. The reporting, requesting and instruction elements of Figure 6 when viewed through the different lenses, represent particular types of informing which have at least the potential to make a difference to the way we think about things or to our disposition to act. As we have pointed out earlier, an instruction exhibited in one lens may invite a disposition to act in a certain way, but this disposition may be inhibited by an instruction exhibited in another lens. So (for example), formal empowerment (as viewed through an administrative lens) does not ensure the taking of initiative, since it may be undermined (for example by lack of trust, as viewed through an anthropological lens).

It should by now be clear that, if our informatic perspective is simply to view a decision system as a simple input-process-output machine, and seek to place a value on (input) information in terms of its impact on its outputs, we are not going to achieve anything which will hold up in practice. Nor are we going to get far with some kind of 'information reservoir' model, in which maintaining some level of 'information position' is deemed a necessary and sufficient condition for decision-taking. In fact:

- no 'single lens' view is going to yield stable and deterministic results on information value, and on the outcome of receiving information – unless we are sure that decision-taking has been 'locked down' to one of purely-objective algorithmic computation;
- different lenses will require different calculi to explain the impact of accumulating information.

On the latter point, we will need to question the inference, that may be drawn from Shannon [22], Boisot [15] and Davenport and Prusak [16], that you cannot be given the same information twice (i.e. it is not information if you already know it). This now seems to derive from a view of a decision system which is exclusively administrative or computational. From an anthropological perspective, it may be (for example) that trust relations require constant reinforcement. So the decision system may need a constant flow of this kind of information just to keep functioning. To interpret the

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[13] Shannon's probabilities pertain formally to objective properties of the world, but his account points to an impact on beliefs and can be easily interpreted in the language of subjective probabilities and Bayesian probabilistic reasoning.

[14] CIBM Task 9, 'Shared situational awareness in the context of the Integrated Approach'.

value of this sort of information properly, we need to focus on the meaning of the *act of transmission*, not (solely) on the data content of the transmission (c.f. Searle's idea of speech acts [23]). We may also need to employ counter-factual logics to argue that the 'difference' (to use Boisot's term) lies in what would have happened had the information *not* been sent.

How can we cope with the 'vertical' messaging between lenses (e.g. the cross-inhibition of activity in one node by a node in another lens)? Finding some general expression of the rules of an information system addressing multiple lenses appears challenging. To make any progress, we appear to need knowledge of the internal architecture of the decision system, for example of the dominant model(s) in use, e.g.:

- Is the decision system being conducted as if it were a computational planning task?
- How highly do the participants rank the avoidance of violations of institutional preferences (and taking a satisficing view of other criteria)?

Another way of asking this is to enquire "What are the critical dimensions of the *cognitive alignment* of the decision systems' participants?" And, clearly, the answers will be pattern-, if not situation-, dependent. This reinforces the conclusion of [21] that there is a real need for a more mature account linking informatics, work and organization.

Complex Adaptive and 'Inquiring' Systems Theory for Contemporary Military Operations: A Multi-perspective Approach

Lorraine Dodd

Anthony Alston

Centre for Applied Systems Studies, Cranfield University.
Defence Academy of the United Kingdom,
Shrivenham, Wiltshire
England, United Kingdom.
e-mail: L.dodd@cranfield.ac.uk

Lorraine Dodd is Director of Research, Centre for Applied Systems Studies, Defence Academy of the United Kingdom. Lorraine is a mathematician with a particular interest in military command and control and more specifically in decision-making and sensemaking in organizations under conditions of complexity. She has applied her craft in the commercial aerospace industry, in the development of military ordnance systems, lecturing in Operational Research at Royal Military College, researching into new algorithms for artificial speech recognition and studying the use of information by decision-makers in complex environments. She has collaborated on US/UK projects for the past twenty years with colleagues from Los Alamos Labs, DoD, Evidence-Based Research, Mitre Corporation, Naval Postgraduate School, and Virginia Tech. She was awarded a QinetiQ Fellowship, she is a visiting Fellow at London School of Economics Mackinder Centre and a Fellow of Operational Research. She sat on the IEE panel for Neural Computing and has been a member of several NATO science and advisory groups related to Command and Control.

Since leaving university Anthony Alston's career has been focussed on the research, design and development of command and control systems; majoring on an understanding of the military processes that the systems support and the doctrine and concepts on which they are based. Following a tour at NATO (the then SHAPE Technical Centre) Anthony joined the Royal Signals and Radar Establishment (RSRE) in the UK, part of which is now QineitQ, researching into air command and control at both agencies. For the past ten years Anthony has been leading research into the definition and understanding of pan-UK Defence digitization initiatives; most notably Joint Battlespace Digitisation (JBD) and Network Enabled Capability (NEC). These have lead to the study of Complex Adaptive Systems as a way of extending the design and development of highly inter-connected and agile organisations and federations of organisations. For a number of years Anthony has been a track chair at the DoD sponsored International Command and Control Research and Technology Symposium (ICCRTS) and is the member of a number of NATO working groups on Command and Control and Complex Systems, including SAS 065, NATO NEC C2 Maturity Model. Anthony is currently Head of the Centre for Applied Systems Studies at Cranfield University, located at the Defence Academy of the UK.

ABSTRACT

Traditionally, military Command and Control (C2) research is focused on problem solution and direct support to decision-taking. Techniques and methods typically involve finding optimal solutions to bounded problems whose objectives span a finite set of options. Such methods are very suitable when the problems under consideration can be represented in closed-process form, when it is meaningful and acceptable to bound the system of interest and de-couple it from its wider operating environment for the purposes of achieving a solution or a decision-action.

Contemporary military operations present a major challenge to C2 theory and methods as they tend to be carried out in theatres and environments where there are increasing degrees of open-endedness (particularly in terms of the extent of effects and consequences of actions) and complexity[1] (both in terms of unpredictability and social diversity). Is it enough to extend and adapt existing methods or do the challenges demand a return to holistic, inquiring systems thinking; such as proposed by Churchman[2] and Ackoff[3]? The latter will require a transformation from objective functions towards subjective representations and a move from preparing for the probable to being able to engage with the possible; such as proposed by post-Keynes economist Shackle[4].

The paper discusses approaches that are proving to be useful for addressing complex problems, where it is necessary to adopt different perspectives and multiple viewpoints. A conceptual framework is presented from which analytical frameworks can be drawn such that the methods used for problem analysis have sufficient degrees of freedom and requisite variety to match the characteristics of the challenges posed by contemporary military operations. A recent case study to address Counter-Improvised Explosive Devices (IED) in Afghanistan will be used to illustrate the conceptual and analytical frameworks.

BACKGROUND: MEETING GLOBAL CHALLENGES THROUGH OPEN INQUIRY

Recently General John Kiszely[5] summarised the challenges facing governments:

> "[they] are characterised by four things in particular: complexity, ambiguity, uncertainty and volatility and by the fact that they all tend to be 'wicked problems' – problems that are intractable and circular with complex inter-

1 As articulated in recent military doctrine and concept papers covering Effects-based Operations and Comprehensive Approach and in J. Kiszely, 'Coalition Command in Contemporary operations.' Williamson Murray(Ed) *Democracies in Partnership: 400 years of Transatlantic Engagement, 2008.*

2 C. W. Churchman, 'The Design of Inquiring Systems: Basic concepts of systems and organisations', Basic Books, 1971.

3 R. L. Ackoff, 'Methods of inquiry,' Educational Publishers, 1950.

4 G.L.S. Shackle, 'The Origination of Choice,' 1986, in Kirzner, editor, *Subjectivism, Intelligibility and Economic Understanding*.

5 John Kiszely, 'Coalition Command in Contemporary Operations.' in Williamson Murray (ed) *Democracies in Partnership: 400 Years of Transatlantic Engagement, (2008).*

> dependencies – where solving one problem can create further problems or make the whole problem greater."

The challenge for strategic analysis therefore is how to approach these types of problems. Two alternatives are possible:

- Extending and adapting existing analytical methods.

- Returning to holistic, inquiring systems thinking, such as proposed by Churchman[6], and Ackoff[7] resulting in a transformation that includes 'traditional' single-viewpoint, objective functions together with subjective, multiple perspective representations. Also embracing work by Shackle[8] who addressed imagined variability rather than expected variance; in essence, possibility rather than probability.

Taking the first of the two alternatives, it is useful to turn to Bertalanffy[9] to understand the conditions under which it might be appropriate to extend existing analytical methods that rely on classical science (i.e. that assume independent and dependent variables within a bounded problem formulation) in order to *solve* the problem – and most importantly where not to extend them.

Bertalanffy identifies two 'classical science' approaches. The first concerns the reduction of a problem into its constituent parts:

> "This is the basic principle of 'classical' science, which can be circumscribed in different ways: resolution into isolable casual trains, seeking for 'atomic' units in the various fields of science, etc. The progress of science has shown that these principles of classical science – first encountered by Galileo and Descartes – are highly successful in a wide range of phenomena.
>
> "Application of the analytical procedure depends on two conditions. The first is that interactions between 'parts' be non-existent or weak enough to be neglected for certain research purposes. Only under this condition, can the parts be 'worked out', actually, logically and mathematically, and then be 'put together'. The second condition is that the relations describing the behaviour of the parts be linear; only then is the condition of summativity given …"

And the second that treats the elements of the problem statistically:

> "…or are the statistical outcome of an 'infinite' number of chance processes, as is true of statistical mechanics, the second principle of thermodynamics and all the laws deriving from it."

He then goes on to reason:

6 C. W. Churchman, 'The Design of Inquiring Systems: Basic concepts of systems and organisations,' 1971.
7 R. L. Ackoff, 'Methods of inquiry,' Educational Publishers, 1950.
8 G.L.S. Shackle, 'The Origination of Choice,' 1986, in Kirzner, editor, *Subjectivism, Intelligibility and Economic Understanding*.
9 L. von Bertalanffy. *General System Theory: Foundations, Development Applications*. George Brazilier, New York, USA, 1969.

> "… The classical modes of thinking, however, fail in the case of interaction of a large but limited number of elements of processes. Here those problems arise which are circumscribed by such notions as wholeness, organisation and the like, and which demand new ways of thinking."

These points can be summarised in Figure 1.

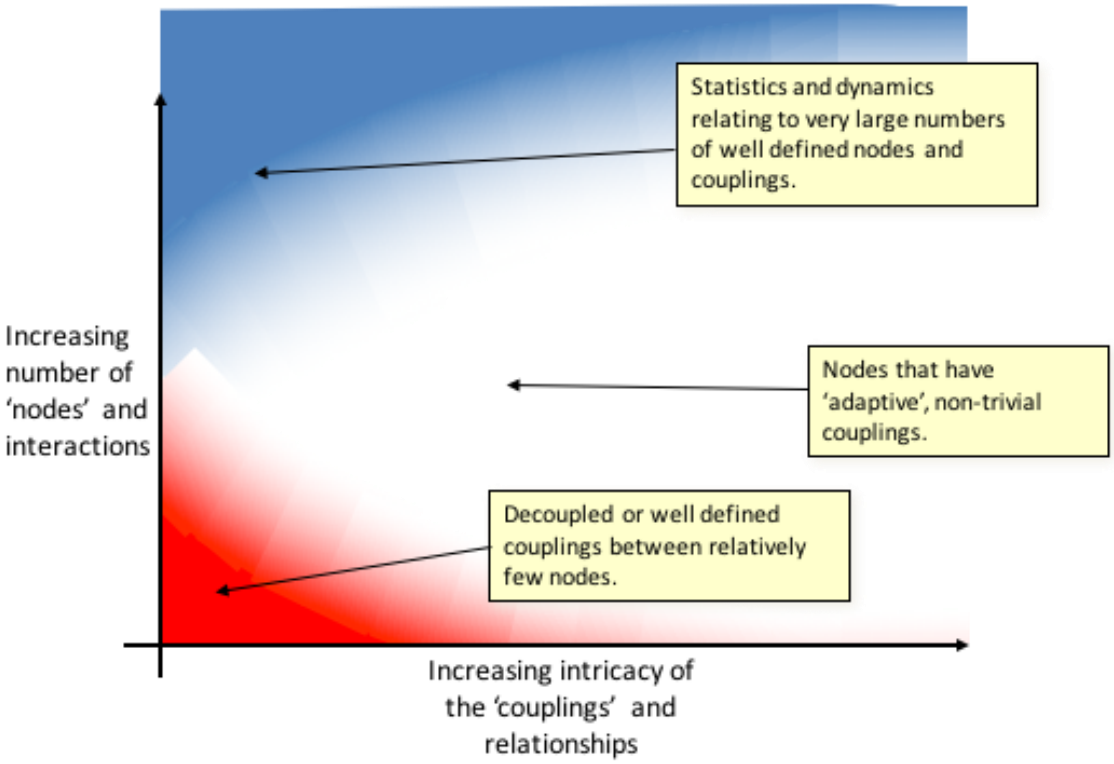

Figure 1: Classical and non-classical problem-solving approaches.

The red area in the bottom left-hand corner includes systems or problems that have 'few' interacting nodes or elements and where the couplings between the nodes are well characterised and understood (Norman and Kumas[10] call this characteristic of interaction 'intricacy' to differentiate it from 'complexity' which brings with it many other characteristics).

The blue area in the top left hand corner contains those systems or problems where there are many (tens to the tens) of interacting nodes or elements and where the couplings between them are again well characterised and understood; that is, they are of low intricacy. These problem types can be analysed statistically or simulated through simple, identical software agents (e.g. flocks of birds or shoals of fish).

The white area is that defined by Bertalannfy as being cases where classical science fails because there are either not enough elements to treat the problem statistically and/or the nature of the interacting elements, and their couplings are so intricate as to be intractable to a

10 Norman and Kuras, Engineering Complex Systems, Mitre, 2004.

reductionist approach. It is in this area that the wicked problems described by Kiszely reside, and where the science of complexity (looking at problems/systems that are composed of dynamic, non-deterministic elements and interactions) may be able to offer some insights.

However, it is important also to acknowledge that increased complexity of problems is not due only to an increased number of interactions and interacting elements. It is also due to a potentially unbounded extent of knock-on effects of any actions or activities and, more importantly, social complexity is increased due to the cross-cultural nature of the people involved and the intricacy of couplings and relationships. The major consequence of this is that these types of problems have no 'correct solutions' in the classical sense.

Therefore, we need methods that will allow us to address all aspects of complexity; in particular, the social and personal aspects which demand methods that can provide insight into problems, rather than advocate solutions to problems that relate to unbounded complex adaptive systems.

INTRODUCTION

A previous paper[11] introduced a staged appreciation for open, complex[12] problems (sometimes called wicked problems[13]). It emphasized that any analysis method should not follow a prescribed rational-technical process, as might be appropriate for bounded, complicated problems (often called tame problems).

The method described uses multiple perspectives to extend sensemaking and observation; hence maintaining open minds and open eyes by being able to imagine what might be possible by adopting the viewpoints of others (requiring the analyst to adopt value systems more appropriate to others' viewpoints). This stepping outside one's usual standpoint or sitting above or below one's usual vantage point allows situations to be seen and considered more broadly, more openly and in more depth as appropriate.

As a way of showing the benefits of an open-minds and open-eyes approach, the method draws from people's experiences, in this way helping to gain a sense of going from seeing by being *apart from* the problem, to sensemaking by *being a part of* the whole. In essence, it is much more about gaining insight than it is about finding an optimal solution. The method supports development of multiple perspectives from different stakeholder viewpoints using associated measures that enable the representation of 'attractors' and influences.

This multi-perspective approach should not be regarded as the only method that the analysis team might use, but should be seen as a part of a larger analytical framework. This

11 Dodd, Prins, and Stamp, Going from closed to open: how may we help to make it bearable, ICCS 2007, http://knowledgetoday.org/wiki/index.php/ICCS07/95.

12 Complexity, both environmental and social, arises due to elements being interconnected in unexpected and unpredictable ways, so attention will be turned to social relationships, alliances and associations (actual and possible) to be able to see the potential for possible options, actions and interactions.

13 Rittel, Horst, and Melvin Webber; "Dilemmas in a General Theory of Planning," pp. 155-169, Policy Sciences, Vol. 4, Elsevier Scientific Publishing Company, Inc., Amsterdam, 1973.

analytical framework takes the work of Mitroff and Linstone[14], who suggest that the analysis necessary to examine complex problems should be drawn from a diverse range of approaches, which they partition into three domains; Technical, Organisational and Personal, and the work of Neustadt and May[15] who place an emphasis on the role of Historical narratives in informing on current problems. Hence, the analytical framework presented has four domains. These four domains are summarised in the Table 1.

Domains	World view	Relevance to type of logical reasoning
Technical	Single viewpoint (The modeller) Classical Science (mathematical models and simulations)	Deductive reasoning
Organisational	Multiple viewpoints (All organisations and teams considered) Social sciences, social and organisational structures	Deductive and inductive reasoning
Personal	Multiple viewpoints (All individuals and roles considered) Multi-Perspective Analysis (MPA)	Deductive and inductive reasoning
Historical	Multiple viewpoints (All aspects of each narrative)	Deductive, inductive and abductive reasoning

Table 1: The four domains of the Analytical Framework.

- Technical (Mathematical models and simulations[16]): examines the problem using deterministic and statistical/probabilistic methods such as Mathematical Models, Cause and Influence Networks and Systems Dynamics Models. These methods tend to optimise and give 'an answer' but they are very dependent upon appropriate data being available and 'realistic' assumption-based models. These are the analysis techniques that are commonly used, but they do not take account of social and human issues within the problem.

- Organisational: examines how the ways 'organisations' operate (their culture and ethos) affect the outcome of the problem and any potential solutions. 'Organisations' in this context include nations, social communities and teams of people as well as formal organisations. Social sciences have useful analysis methods and models, for example Morgan's book 'Images of Organisations'[17] presents nine 'metaphors' for the examination of how organisations operate.

- Personal: examines how individuals (a specific person or a role) affect the outcome of the problem and any potential solutions. Its motivation is the same as that for the Organisational domain – it bounds the solution space. This domain is not well supported by techniques– interviewing individuals is one of the methods put forward.

14 Mitroff and Linstone, Unbounded Mind: Breaking the chains of traditional business thinking. Oxford University Press, 1993.

15 Neustadt and May, Thinking in Time: The Uses of History for Decision Makers, Free Press, 1986.

16 The term 'technical' as used by Mitroff and Linstone can be misleading. It does not refer to 'technology' but to what Bertalannfy described as 'classical science'.

17 Morgan, Images of Organization, Sage, 2006.

- Historical: analyses similar or analogous situations to the one being investigated, gathered either from the experience of the participating decision-makers or from history, in order to gain insights into the current problem. The intention is that the analysis should uncover not only similarities between the past and current situations but also where there are differences. This domain is supported by unstructured techniques such as historical analysis and story telling or composing narratives.

The 'weight' given to each of these domains during the analysis is totally dependent upon the nature of the problem, but any investigation should include aspects of all domains. The analytical framework discussed in this document is restricted to the multi-perspective approach (MPA) and only addresses the 'Personal' domain (individuals and/or roles), and aspects of the 'Organisational' domain (teams and groups). However, the approach discussed can be used for all four domains of the full analytical framework. The reason for this comparatively limited coverage is that the authors believe that the 'Personal' domain is particularly poorly supported, yet is the most critical dimension in the social problems faced today.

MULTI-PERSPECTIVE APPROACH (MPA)

It is important, first, to establish the context within which the MPA will be carried out. There are two main types of questions:

- Forward-looking (exploration of options for actions – deductive and inductive reasoning), where one is trying to make judgements about the possible effects of actions / interventions on future outcomes. So here the analytical options being considered are intervention or forward-planning options. For example, *What could be the possible effects of paying $x for IEDs that are handed-in to military authority?*

- Backward-looking (appraisal of hypotheses – abductive reasoning), where one is trying to understand how and why the past might have led to the current state of affairs (as observed, interpreted, etc.). So here the analytical options being considered are hypotheses. For example, *What could be plausible causes of unexpected increase in IED incidents in 2007 during poppy harvest?*

The MPA is more suited to the forward-looking type of question[18]. This was the focus of the C-IED example, and on which this paper concentrates. MPA begins by defining an initial set of stakeholders. So effectively, in the context of a forward-looking analysis, consider the question: "who are the people who potentially have something at stake, given *option x* is being considered as a future option?".

18 Backward-looking questions can be addressed by applying the MPA repeatedly to numerous hypotheses. However, the investigators think that this approach is inefficient. Finding a more appropriate method, based upon the MPA, is an active area of further research.

USEFUL CONCEPTUAL LANGUAGE

So using the reasonably well-understood concept of a stakeholder, the proposed future option will involve a specific item or 'system of interest'. Taking as an illustrative example (covered later in more detail), Countering IEDs in Afghanistan, consider the option of paying for IEDs that are handed-in. Adoption of the viewpoint of any stakeholder will help to see that different stakeholders may have very different reasons for their interest in IEDs (see Table 2 below).

Stakeholder	What defines main interests of stakeholder in IED?
Taliban fighter	IED as effective force element
Ammunition Technical Officer (ATO) Operator	IED as device to be 'made safe'
Local population	IED as personal threat or opportunity
Media reporter	IED as news-story element

Table 2: Different stakeholder viewpoints.

The MPA has a number of analytical concepts that it uses to analyse the impact of paying for IEDs on each of the Stakeholders. These are:

- Stakeholder Viewpoint and Multiple Viewpoints.
- Stakeholder Lines of Perspective and Measures.
- Stakeholder Positioning.
- Stakeholder Options for Action.

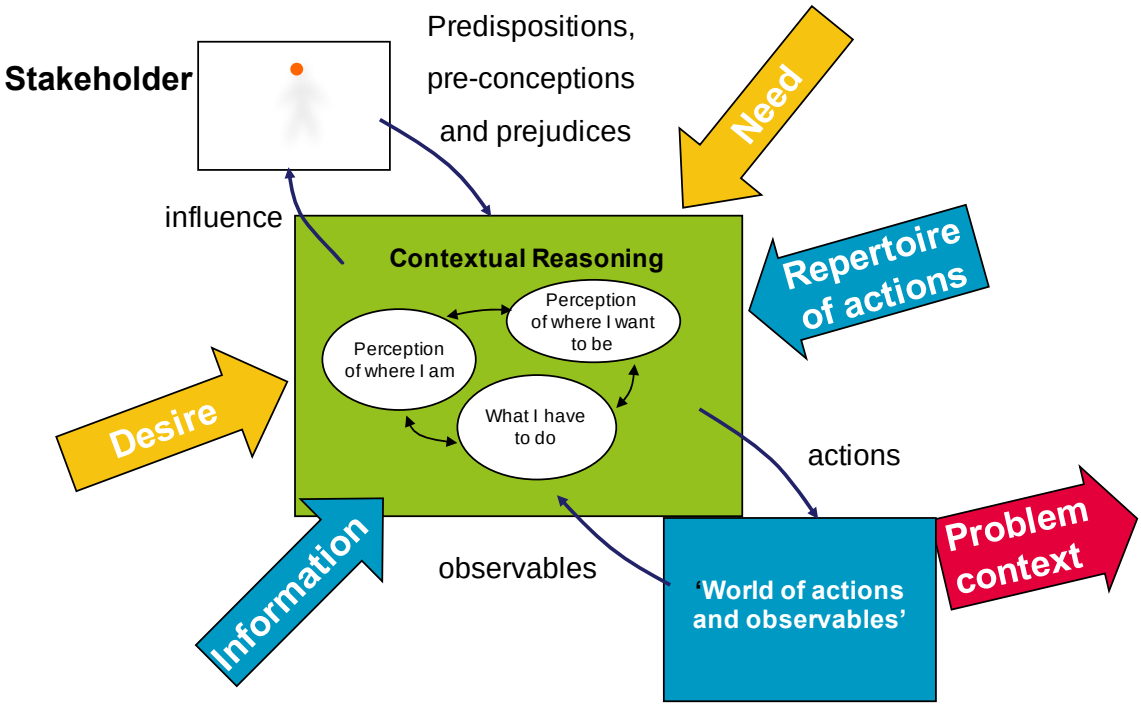

Figure 2: Concept of a Stakeholder Viewpoint.

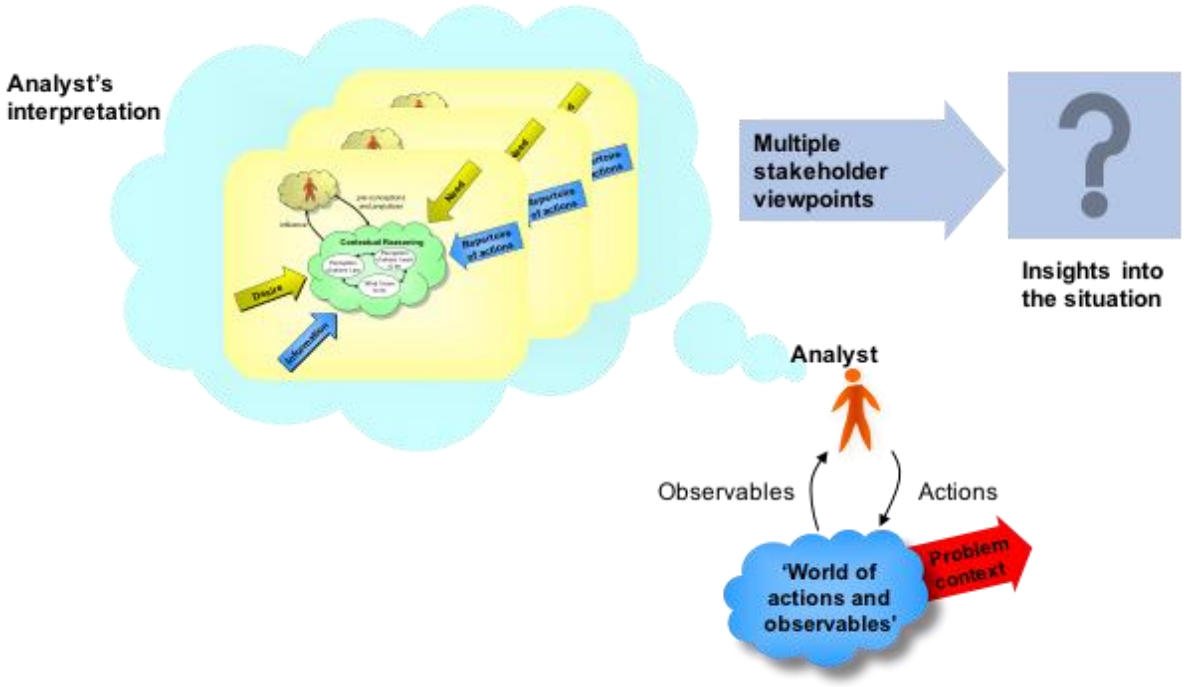

Figure 3: Multiple viewpoints of different stakeholders.

STAKEHOLDER VIEWPOINTS AND MULTIPLE VIEWPOINTS

The viewpoint of each stakeholder (see Figures 2 and 3) is then considered in detail and consists of three parts:

- 'real world' – where all actions and interactions take place and where they and their consequences might be sensed from the viewpoint of a stakeholder. This is termed the 'World of actions and observables'.

- 'background' - the culture, experience, training, prejudices, principles, etc that a stakeholder brings to any situation.

- 'reasoning' - the assumed reasoning a stakeholder does concerning 'what to do' based upon their background and what they observe in the real-world. At the heart of the reasoning is the stakeholder's 'feel' for where they want to be, where they are and the relative difference between the two, which will drive the actions they might take to reduce the distance between the two positions.

There are four main influences involved in the 'reasoning' part:

- The desires of the stakeholder – those aspects of life that the stakeholder really cares about.

- The needs of any stakeholder – the things that are deemed necessary to sustain and maintain life.
- The information the stakeholder receives - noting that what the stakeholder observes and how it is interpreted is very dependent upon and influenced by their background.

- The repertoire of actions that the stakeholder has at his disposal - again is very dependent upon and influenced by their background and (the individual and institutional) context.

STAKEHOLDER LINES OF PERSPECTIVE AND MEASURES

Figure 4 shows in outline the construction of a perspective for a single stakeholder viewpoint. It is easier to understand the conceptual language relating to a perspective as an analyst might construct a landscape within which to consider stakeholder positions.

- Any perspective is formed from a standard set of candidate lines of perspective (LOP) but the relevance and weighting given to any single LOP is determined by the stakeholder viewpoint and the problem context (e.g. a stakeholder may be positioned according to a financial or contractual perspective more than they would a social perspective).

- The analyst opens up discussion about which lines of perspective are of most importance to the stakeholder, given the context of the problem.

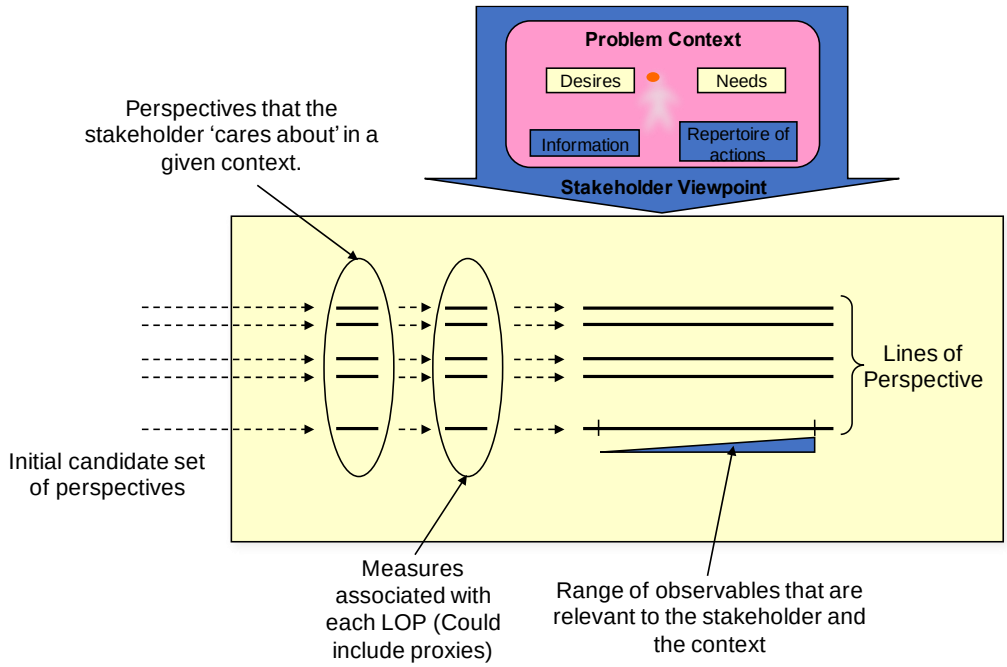

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Figure 4: Stakeholder lines of perspective and measures.

- For each of the chosen lines of perspective a measure must be identified that offers a sense of scale along which stakeholders positions can be placed.

- For each measure on a line of perspective the relative end-points subject to that stakeholder in that context are initially defined.

STAKEHOLDER POSITIONING

Across the lines of perspective a 'positioning vector' can be plotted that relates to a desired position (i.e. a position of relative stability or an attractor in that stakeholder's landscape). Each position does not have to be represented as a line (i.e. resulting in a point attractor on the landscape) but could be a region of attraction, indicating a region where conditions could be assumed to be relatively stable. It is shown in Figure 5 that Desired and Perceived Position vectors, and the measure of the difference between the two, may provide insight for the stakeholders' motivation or drive to act.

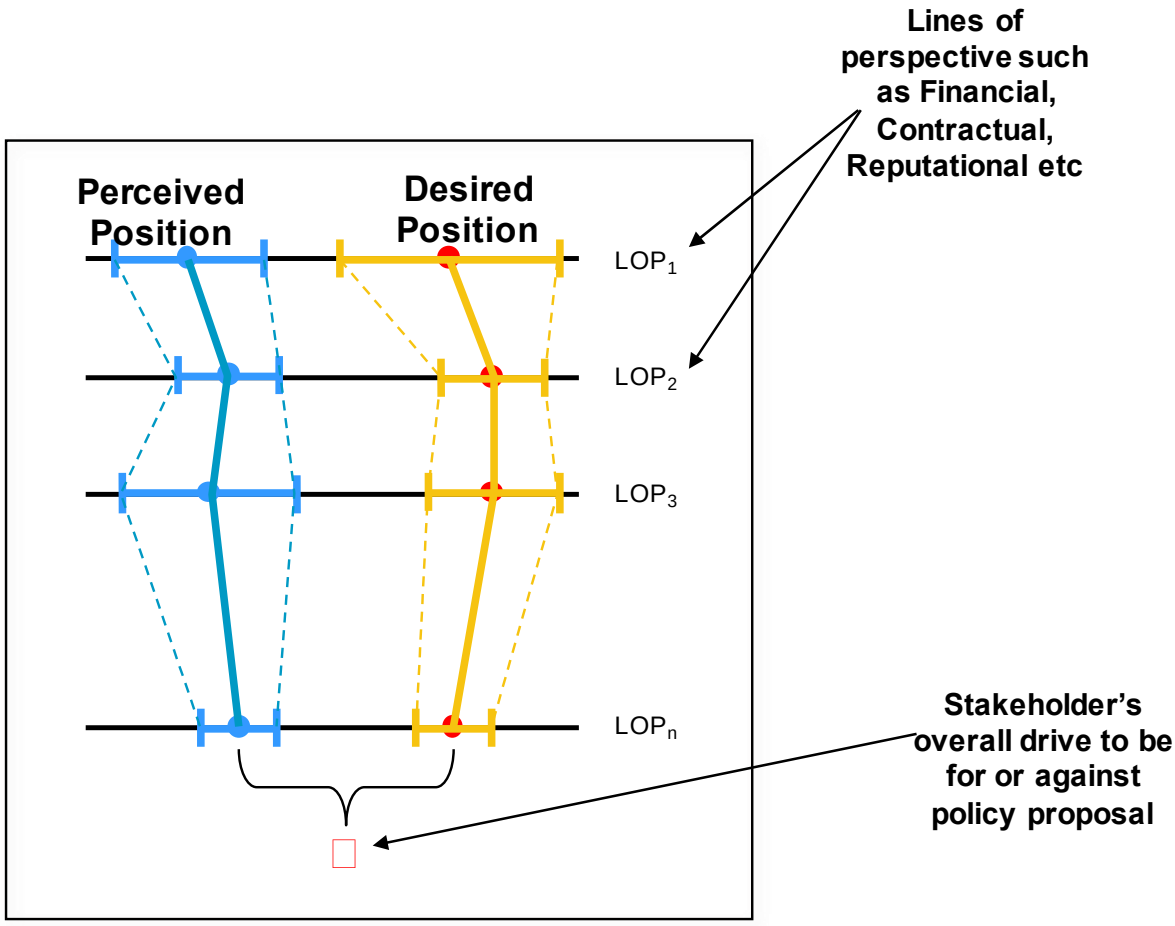

Figure 5: Stakeholder Positioning.

STAKEHOLDER OPTIONS FOR ACTION

The final concept that requires explanation before the full analytical framework is discussed is the 'Stakeholder Options for Action', which essentially is a list of practicable actions that any stakeholder might consider adopting or undertaking.

This concept, shown in Figure 6, embodies the thinking of Clausewitz[19] and Turing[20], having three main elements relating to order, drive and resultant variety (constraints/restraints, motivations/myths and options/actions). The concept states that the range and types of actions or options available to any stakeholder is directly related to their means (i.e. constraints on availability of materials they have to do things with), moderated by the stakeholder's drive (which can be simply thought of as the stakeholder's motivation – the more motivated the more likely the stakeholder is to undertake extreme action) - and the order (restraints that come from the governance rules or laws that the stakeholder has to abide by).

19 http://www.clausewitz.com/CWZHOME/Trinity/TrinityTeachingNote.htm
20 *The Chemical Basis of Morphogenesis*, *Phil. Trans. R. Soc. London B* 237 pp 37-72 (1952).

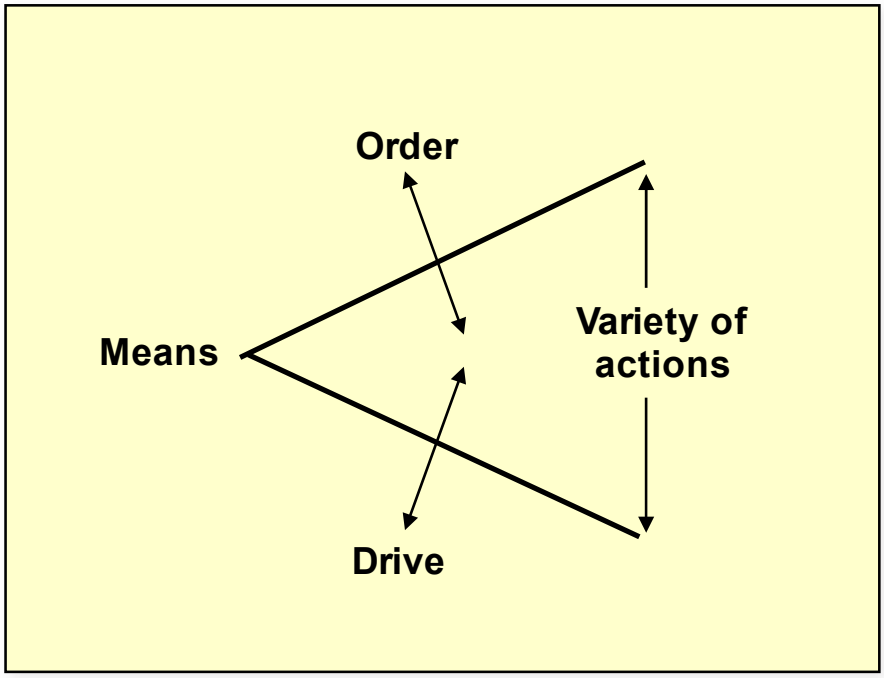

Figure 6: Options for Action

BRINING THE CONCEPTS TOGETHER

Within a particular problem or issue context, we can construct the stakeholder's Perspective as previously described, which captures their Desires and Needs. The Stakeholder's assumed reasoning about any Desired position are set within their particular perspective. Such reasoning about placement of desired positions will question assumptions being made about stakeholder priorities (Lines of Perspective) and values along which their perspectives are being developed, discussed and drawn (see Figures 7 and 8).

From the 'World of Actions and Observables' the analyst can begin to discuss what stakeholders may be attending to and how such things may be being perceived and interpreted. This allows an initial estimate to be made about where the stakeholders' Perceived Position might be, as set within their particular perspective. This initial inquiry into stakeholder positioning should also help to expose assumptions inherent in the analyst's own 'information' filter (what he can and cannot see and how the analyst perceives it).

AN ANALYTICAL FRAMEWORK

The comparison between the Perceived Position and the Desired Position helps to understand where it might be easier to influence others' actions. There are three main ways in which future options can be explored (see Figures 9, 10, and 11).Analysis Type 1 (Figure 9): Stakeholder Impact Analysis: explores the potential impacts of one stakeholder's possible actions on the others.

a. The possible courses of action for each stakeholder are articulated.

b. Any one chosen course of action for any one stakeholder is 'played through' set against the other stakeholders' Perspective Landscapes to see how it might affect their Perceived Position, their lines of perspective and/or their desired position; leading ultimately to the drive that may change the repertoire of actions.

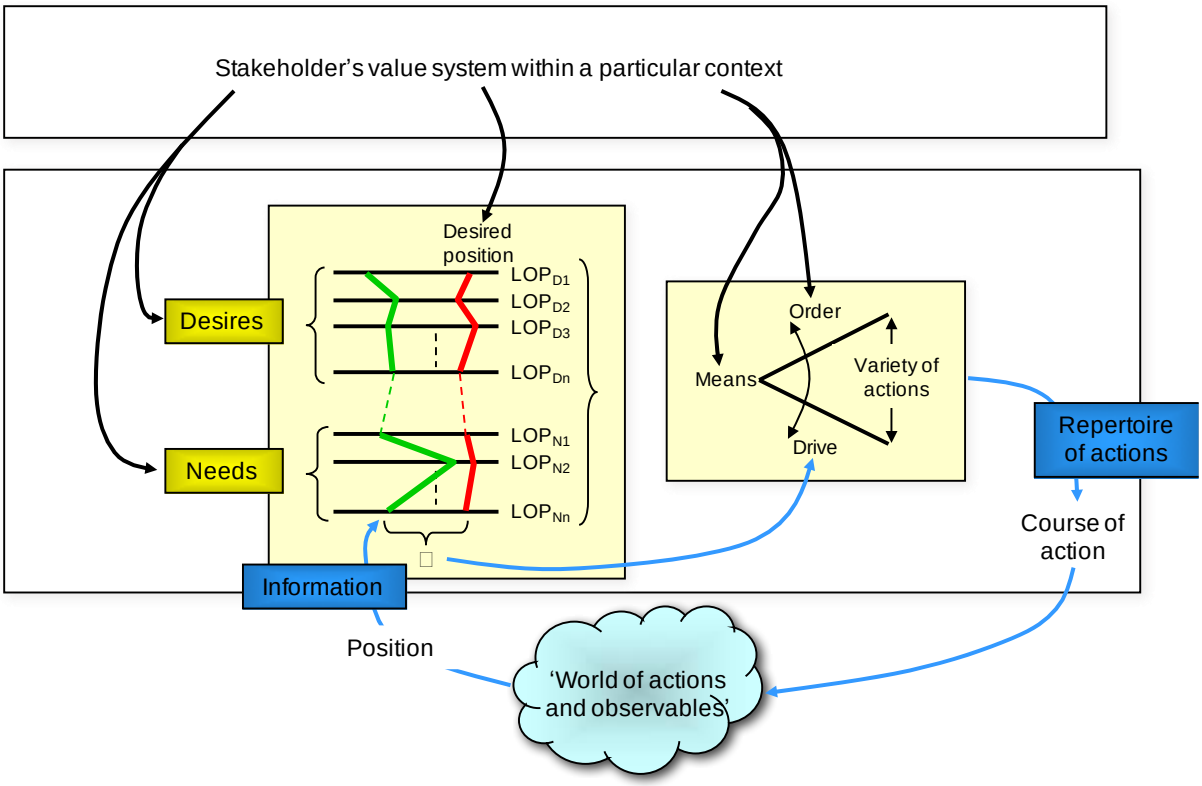

Figure 7: Analytical framework: single stakeholder.

c. This is carried through for other stakeholders to provide an indication of how each might then be affected or might respond to possible actions by the others.

Analysis Type 2 (Figure 10): Innovative analysis. Encourages development of innovative options which are outside all the stakeholders' repertoires of actions but which may work to move people to more relatively stable positions.

a. The possible courses of action for each stakeholder are brought together to form an overlapping range (or a number of contiguous ranges).

b. An option outside the bounds of these ranges is imagined.

c. The new 'innovative' option is played-out (as in 1 above) to provide insights into potential responses and possible changes in positions/perspectives.

Analysis Type 3 (Figure 11): Cross-framework analysis. Integrates across the stakeholders to provide an indication of their underlying differences and possible dialectics.

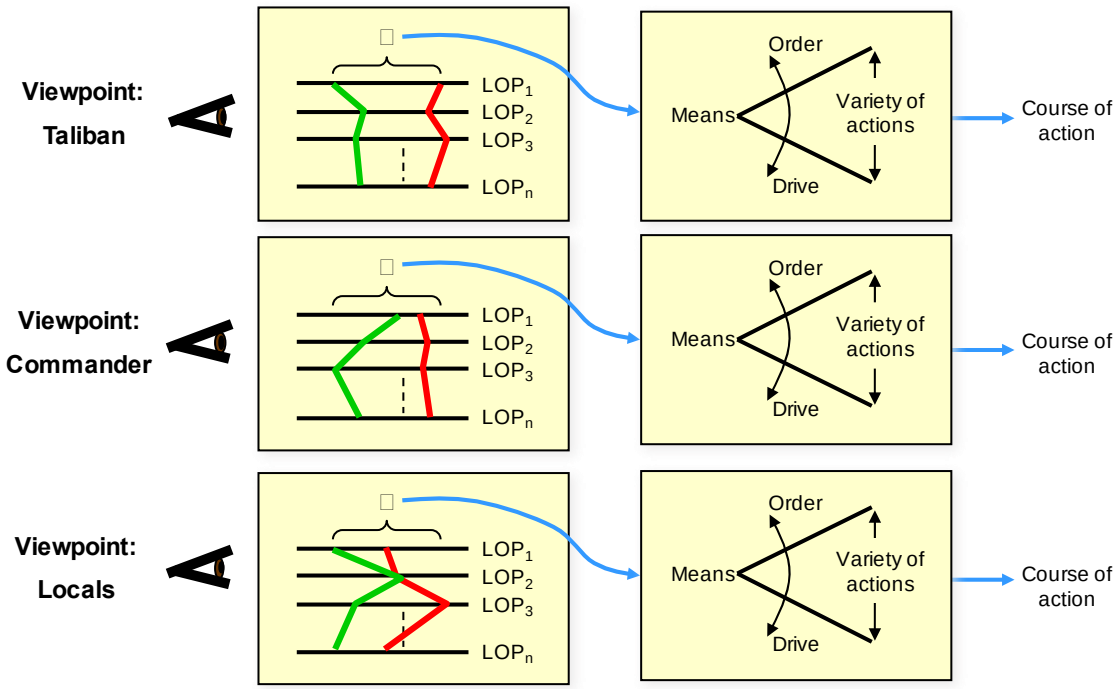

Figure 8: Example using Afghanistan CIED showing just three stakeholders.

a. The Perspective Landscape for each Stakeholder will be different, not only in terms of the particular Lines of Perspective, but more importantly in terms of the measures and relative metrics on the common Lines of Perspective. For comparison each perspective needs to be translated into a common form.

b. Once the translation has been done the perspectives can be compared to provide an indication of the underlying differences between the stakeholders. This could help inform the mechanisms needed to support collaborations.

c. If the translation into a common form is not possible then bi-lateral comparisons may have to be made.

Identifying an action to take is only a part of the analytical process. An action taken could change parameters within the analysis, so it is essential that the whole analytical framework is cycled round as part of an 'action-analysis' loop.

SUMMARY

This set of concepts and the resulting analytical framework shows the two phases of constructing the analytical framework; the initial analysis of the stakeholder's value system within a particular operational context and the cycling analysis of the actions and observables. However, these two phases should not be thought of as independent. For example, changes in the 'system under analysis' could change the context of the initial stakeholder analysis and influence and change their value system.

The Analytical Framework proposed here is adaptive – in that its 'structure' changes as the situation changes. This is apposed to a 'dynamic' framework that can take a range of inputs (variables) but does not change its form. This affects how the Analytical Framework is used for each type of question.

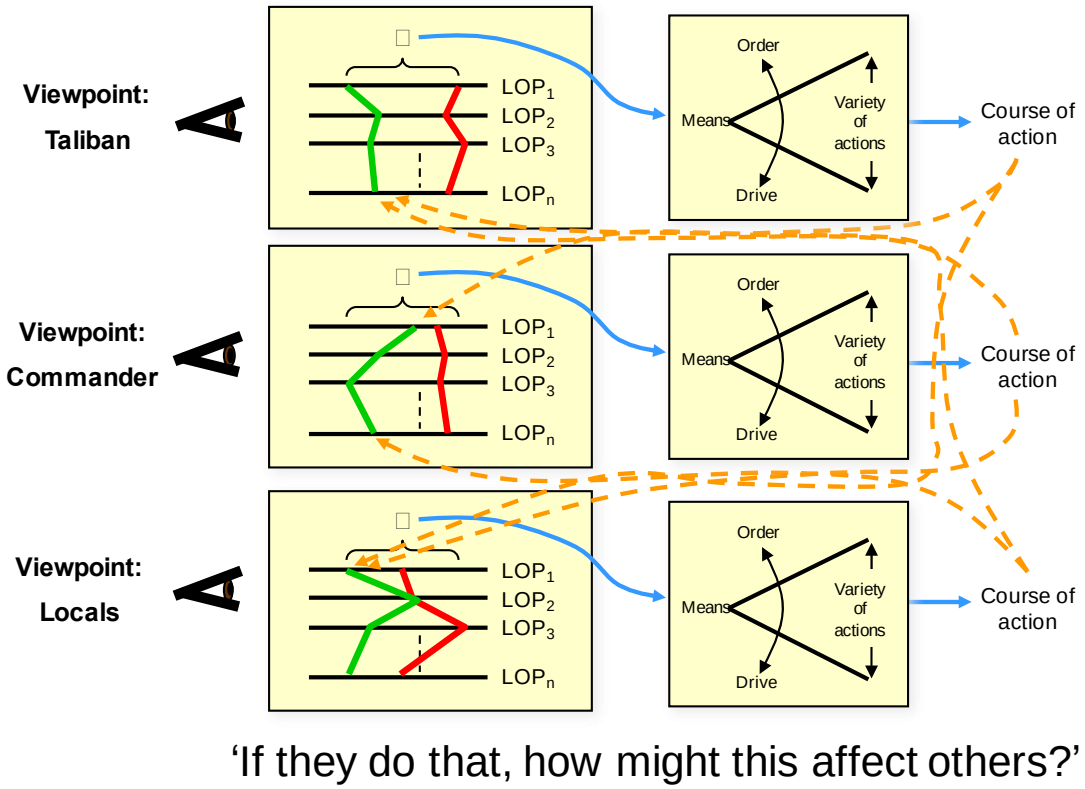

Figure 9: Analysis Type 1: Exploring stakeholder impact.

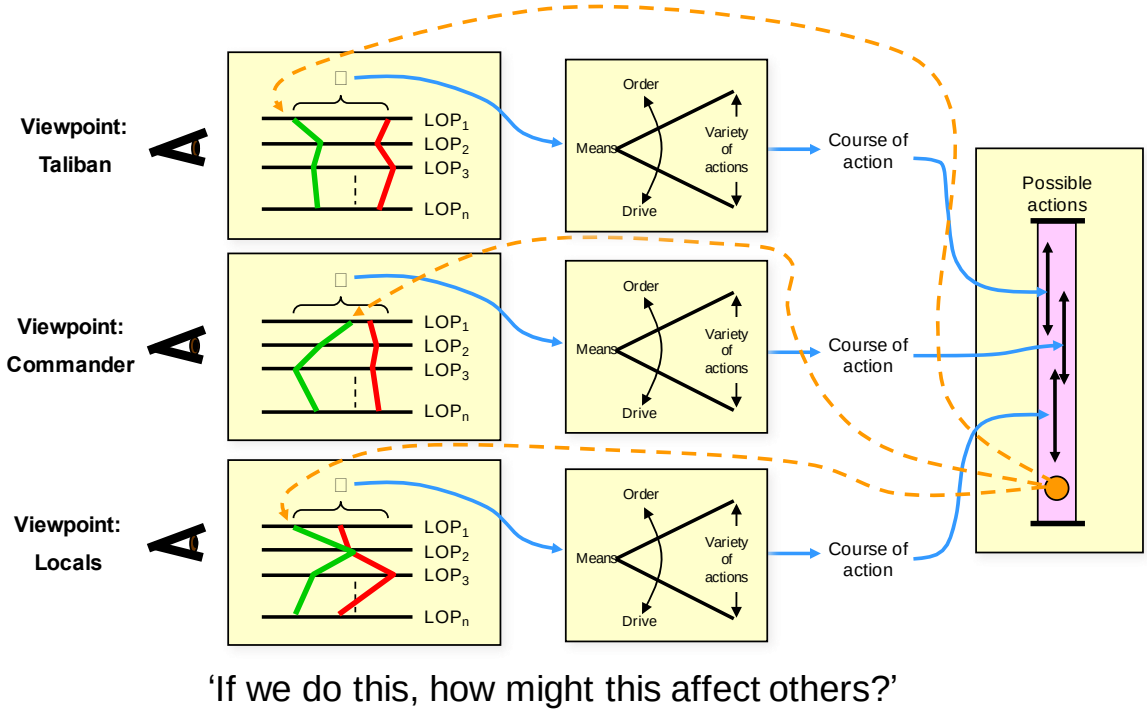

Figure 10: Analysis Type 2: Innovative options.

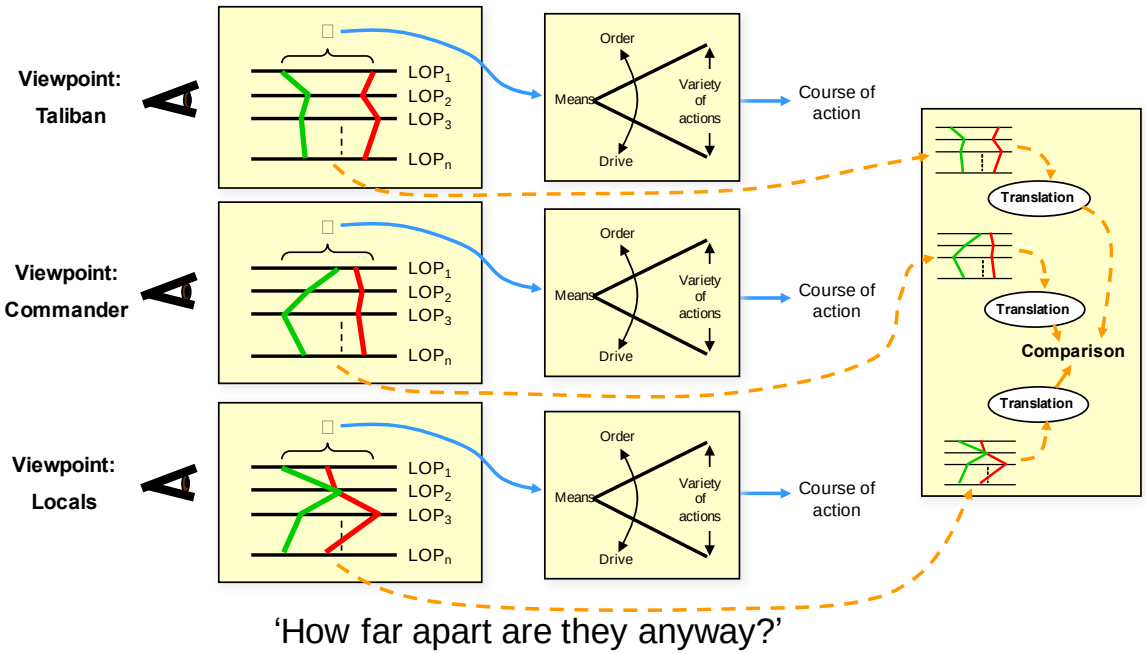

Figure 11: Cross-framework analysis.

AN ILLUSTRATIVE EXAMPLE

The illustrative example is derived from analysis work carried out for United Kingdom's (UK) counter-terrorism centre and relates to questions that were being considered regarding the Prevent options for counter-IED in Afghanistan.

There were two candidate questions chosen to illustrate the analytical framework:

- Forward-looking question:
  - Is it deemed reasonable to pay $x for IEDs to be handed-in?

- Backward-looking question:
  - Why did the number of IED incidents not decrease during poppy harvest in 2007?

Within the adaptive analytical framework, backward-looking questions are very challenging due to the multiplicity of frameworks required and so the illustrative example is based on the forward-looking question, which then sets the context for the analysis.

The context of the question is the Counter IED campaign in Afghanistan.

An initial list of stakeholders is drawn-up and is left open-ended…:

- Coalition Command
- Ordinary Solider
- ATOs (i.e. IEDD operators)
- Local population (Collateral)
- Local population (Protection)
- Bomb operatives (including finance & training)
- Afghan forces (including police)
- UK Public
- UK Government
- Tribal Elders (including District Councillors)
- Taliban
- Businessmen (Legitimate)
- Non-Governmental Organisations (NGOs)
- Afghan Government

- Businessmen (Non-legitimate) (including narcotics/weapons trading)
- Media

- UK Analysts (Intelligence etc.)

- …

This list includes broad classes and individual roles. As the analysis progresses it may become necessary to divide some of the initial stakeholder classes into sub-classes or it may be deemed reasonable to group together different classes into a combined class. So there could be many more then those listed; for example, Local Population, may be too broad. Issues such as these will be teased out as the analyst cycles through a number of iterations of the framework. This illustrative example represents a single cycle only.
The first check is to consider the key contextual element, which in this case is IEDs, as the particular system of interest and ask:

What defines the main aspects of stakeholder interest in IEDs?

So if we select just four of the stakeholders[21] their interests in IED could be summarised as listed in Table 3.

Stakeholder	What defines main aspects of stakeholder interest in IED?
Taliban	IED as force element
ATO Operator	IED as device to be 'made safe'
Local population	IED as personal threat or opportunity
Media	IED as news-story element

Table 3: The Interest in IEDs for four Stakeholders.

So an immediate candidate for division is the stakeholder class 'local population' because they could view IED either as a personal threat or an opportunity.

Now we need to consider perspectives. To create a Perspective Landscape for each stakeholder viewpoint we start with a list of potential Lines of Perspective. These represent the nature of the aspects of the situation that the stakeholder cares about and as such are assessed for relevance to each stakeholder. If it is felt that any perspective could have at least two possible implications for that stakeholder then the stakeholder class may have to be divided into two sub-classes.

21 The illustrative example only develops four stakeholder viewpoints and so these were chosen to represent a reasonably diverse range of viewpoints.

Each stakeholder viewpoint is adopted in turn and if the answer to the question (from their viewpoint) about taking a certain perspective is 'yes' then that line of perspective must be included in the framework for that viewpoint. For example:

"Do I care at all about my situation from a perspective which is:

- Geographical
- Financial
- Professional
- Emotional/spiritual/sensational
- Social
- Societal
- Operational
- Analytical
- Organisational
- Political
- Ideological
- ….. others..?"

If so, then I am likely to have a sense of my position (both desired and perceived) in a landscape explained and under-founded by those lines of perspective.

Finally, Measures are identified for each Line of Perspective.

Table 4 shows an initial build-up of lines of perspectives as we work through the stakeholder viewpoints with suggestions for associated measures that will help to place and discuss desired and perceived positions.

Stakeholder	**What defines main aspects of stakeholder interests in IED**	**line of perspective**	**Measures**

Stakeholder	What defines main aspects of stakeholder interests in IED	line of perspective	Measures
Taliban	IED as force element	• Geographical • Financial • Educational • Ideological • Social • Technical • Organizational • Political • Operational	• No. of regions of influence • Level of self-financing • number of schools • % signed-up to ideology • Taliban with referent power • numbers with IED skills • % positions of authority • Degree of Governmental power • % reqd operative status
ATO Operator	IED as device to be 'made safe'	• Geographic • Professional • Social • Operational • Technical • Analytical • Organizational	• % geography = safe areas • Degree of achievement • Extent of social knowledge • % reqd operative status • Extent of device knowledge • Amount of support • Degree of autonomy
Local population	IED as personal threat or opportunity	• Financial • Commercial • Physical infrastructure • Freedom of movement • Social	
Media	IED as news-story element	• Geographical • Emotional/ sensational • Societal • Operational • Analytical	

Table 4: Stakeholder Viewpoints and their Lines of Perspective.

Discussions and inquiry into stakeholder perceived positions will then help to highlight issues about their ability to be able to attend to and focus on particular lines of perspective.

It is then possible to explore any knock-on effects of your considered option (e.g. in this instance, pay $x for IEDs to be handed-in) on each of the measures along each line of perspective to see the imagined impact that taking the action may have on each stakeholder by examining whether the Measures would reduce or increase the delta between their Perceived and Desired Positions. We would also have to consider the possibility that an action could have both a positive or negative effect, which would indicate that dividing the Stakeholder class may be beneficial to the analysis.

It is interesting to explore effects of actions that could result in a line of perspective being added to *the initial set for a particular stakeholder.*

Taking for example the Local Population as a stakeholder, there is a possibility that paying for IEDs will add a financial Line of Perspective where one did not already exist[22].

So stakeholder actions could result in either of the following:

- Movements in perceived position.

- Movements in desired position:
  - Either by changing the measurement scale;
  - Or adding/removing a Line of Perspective.

The illustrative example has shown the potential for providing and developing cross-stakeholder insights. It opens up inquiry and encourages open discussion, especially when done in conjunction with other analysis techniques. It helps to expose hidden assumptions and prejudices and helps to support collaboration by uncovering dialectics and encouraging innovative actions and self-reflection.

CONCLUDING REMARK

The small amount of work so far undertaken with the MPA has provided a glimpse of its potential. Within this discussion paper, the illustrative example has been primarily concerned with the forward-looking analysis of potential actions, where the reaction to any action can only be investigated in the Personal and team and group aspects of the Organisational dimensions. However, there is nothing within the analytical framework per se to exclude such 'impact analysis'. Indeed, this extension of MPA is an ongoing programme of work within the Centre for Applied System Studies at Cranfield University.
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22 Following instances of payment for IEDs handed in to military HQs, there was establishment of market prices and exchange deals for IEDs in return for video capture of their subsequent explosion.

Techne and Techniques for Engaging in a Socially Complex World

Abstract

This paper addresses the challenge for Operational Research (OR) in extending out from traditional forms of modelling towards a more relational form of modelling. The challenge comes from OR practice becoming more transformative in nature, which puts more emphasis on reflective practice, people and relationships. Staged Appreciation is proposed as an overall guiding framework and selected illustrative techniques are presented for engaging with social complexity; so-called "wicked" problems. Systems Thinking techniques, guided by Staged Appreciation add an insightful new dimension to knowledge sharing for understanding, and for reflecting upon the intricacies involved in socially complex situations.

There are analytical advantages of standing apart from complexity. Staged Appreciation complements this analytical standpoint by asking analysts to take a more reflective view of their own working relationships, being more *a part of* the socially complex problem as well as standing *apart from* it. Staged Appreciation offers a reflective framework for working with Systems Thinking techniques and together they complement traditional practice. The proposal and suggestions aim to support analysts to adopt a more reflective and relational view of a complex problematic situation in order to see it 'as a whole'. The paper draws lessons from holism, reflective practice and subjective analysis.

Keywords: Soft Systems, Methodology, Practice of OR, Multi-Objective, Heuristics.

Background to identify the practice gap

Over several years of running courses on systemic thinking and reflective practice for complex situations, attended by government analysts, it has become more apparent that analytical skills might benefit from a more subjective approach. The situations tend to be more socially and relationally complex (Ulrich and Dash, 2013), and any interventions and proposed solutions may therefore need to be "clumsy" resolutions (Thompson, 2008).

As "OR projects have become increasingly participative" (Ormerod, 2008), and the projects that analysts are involved in have become more interconnected, there may be a call for more reflective practice. This asks the analyst where they stand in relation to others involved in the situation. This perhaps calls for a second look at "OR competencies" where analysts need to have an "ability to self-assess" (Ormerod, 2013).

Introduction to socially complex situations

Any problem that has you, as an analyst, involved in it, by definition has you, the analyst, as *a part of* the problem. If OR is to address socially complex problems then there may be need for some complementary techniques that will help to:

- Look at people as people and not as "things" (e.g. nodes in a network, resources);
- Being subjective as well as objective; for example, seeing situations from a subject's perspective as well as from an analytical perspective;
- Broaden focus so that compromise solutions might be found that go beyond the usual objective indicators and measures that lead only to a single-point optimal.
- See the problem from different perspectives (e.g. so what seems to be "the best" from one perspective can be resolved for situations with multiple stakeholders)
- Highlight the interactions between things and events; and, more importantly, the intricacy of relationships between people (i.e. couplings, social bonds);
- See the problem as a whole.

Today's problematic situations are becoming more complex (Bar Yam, 2005), where increasing complexity tends to be attributed to an unbounded number of elements and interactions and an increasing rate of events. Previous papers on so-called "wicked problems" (Churchman, 1967), (Roberts, 2000) and previous studies (Dodd and Alston,

2009) have suggested that complexity has another important dimension, which relates to the increasing intricacy of couplings and inter-relationships. It is the nature of this inherent inter-relational intricacy that forms the context for this paper.

When problems are looked at objectively, they tend to be viewed in terms of the quantitative dimension of complexity. The inherent social and personal complexity of human systems (Vickers, 1983) is not being addressed. So the first question that this paper poses is: "What is available to help OR analysts appreciate more fully the intricate, personal and relational nature of the complexity in the situation as a whole?"

This paper proposes Staged Appreciation as a form of techne, which captures the essence of what it is to master a skill, and as such could be used as a guiding check-list as OR analysts work with people through complex problems. This check-list approach is in the spirit of Dr Atul Gawande, as in his 2014 Reith Lectures he proposed such an approach to aid with "the messy intersection of science and human fallibility".

Staged Appreciation (Dodd, Alston and Stamp, 2010) follows six inter-related stages:

- Where people are: this acknowledges that 'where *people* are' is the most important consideration, and that this positioning of people has many aspects; so it could be in socio-geographical/demographic terms, and socio-cultural/political terms and it could be in terms of their capacity for sensing the extent of the situation and for making sense of the unbounded complexity of the situation.
- Open-eyes/open-mind: explicitly addresses how people might be approaching their sensing and sense-making; so, for example, if people are only looking at the pre-defined indicators or parameters and using extrapolation of past indicator-based trends, then this closed-eyes/closed-mind approach, in itself, forms a large part of the broader problematic situation.
- Belief and surprise: elicits what people believe through asking what might surprise them (see Figure 1); so, for example, if people have been greatly surprised by the consequences of a considered decision, (e.g. believe that use of method A will help to solve problem X) then they are more likely to openly appreciate and reflect on their previously held belief about what could happen and adapt accordingly.

- Choice-making and choose-ables: suggests that people's choose-ables tend to limit and colour their views on a situation; so, for example, if people can only consider or countenance two ways forward, then the situation will be viewed in black and white or 'us-them' terms. If people can be helped to see beyond their current or comfortable ways forward and to relate to others' choose-ables, then this proffers more open understanding of the potential benefits of novel options for resolution.
- Focus and preference: are intricately related to belief and choose-ables; so, if all of these can be openly appreciated then 'where people are' (especially in terms of open-eyes and open-mind) can be addressed as being part of the problem situation. This applies directly to the analyst or the problem structurer or facilitator.
- Multi-perspectives: can now be appreciated with a richer understanding of the diverse range of people's views, and of people's deeply held lines of perspective, that can be hidden deep within a problematic situation, when ways of being and doing (i.e. their Weltanschauungen, as discussed later) are dear to people's hearts, minds, behaviours and lives.

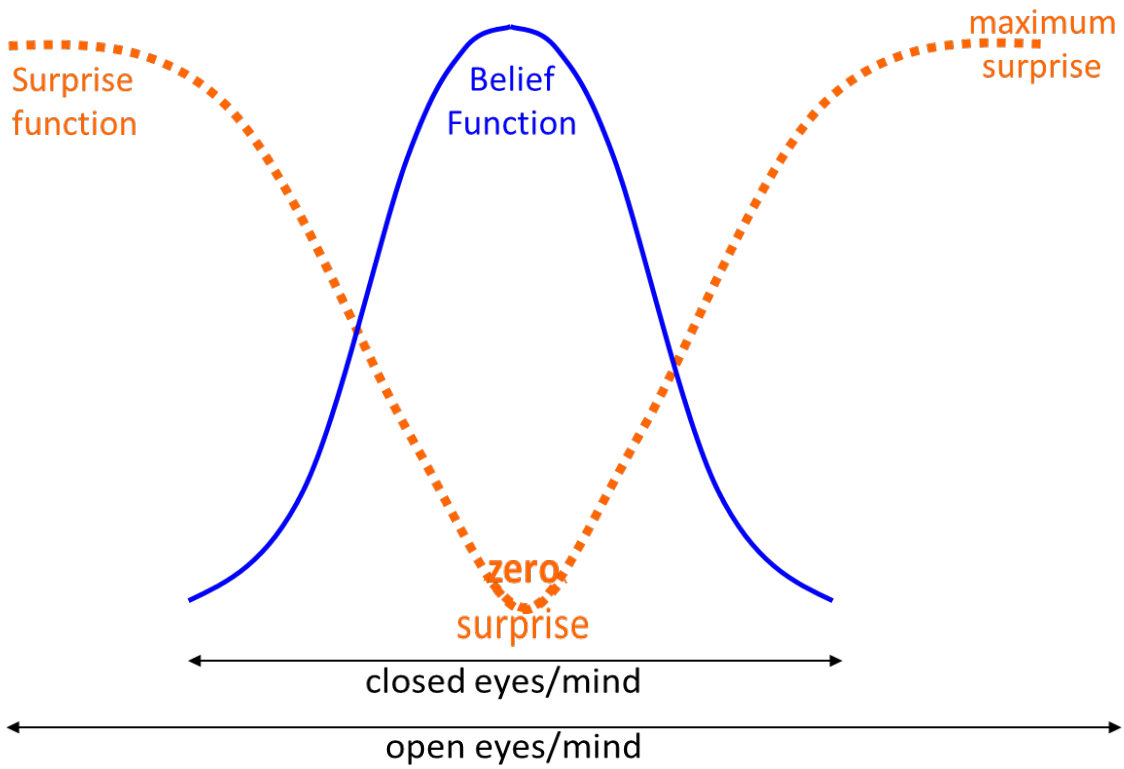

Figure 1: Surprise as the inverse function of belief relating to open-eyes/open-mind.

There are other useful frameworks such as Critical Systems Heuristics (in Ulrich, 2003) to show how holding to a single analytical measure of success can dominate analysis, such that it determines problem-solutions and limits perspectives. CSH can mitigate against particular measures of success (MoS) dominating analyses by making the MoS explicit and linking the MoS directly to those involved, who may be working through power dynamics to serve their own interests rather than seekng shared interests. CSH is now discussed further in relation to Staged Appreciation, Problem Structuring Methods (PSM) and System of Systems Methodology (SOSM).

A view of the landscape

The academic and practice-based landscape of the development of OR and Management Science (OR/MS) is comprehensively reviewed in (Jackson, 2006), in which the framework for positioning Problem Structuring Methods is defined using categories of problem: simple or complex; set against natures of participation: unitary, pluralist, coercive (adapted from (Flood and Jackson, 1991)). Rather than arrange methods and approaches as a segmented framework, which assumes a problem structurer's categorisation of the landscape, Figure 2 here depicts a nested view of that landscape. Following from (Ulrich, 2017), the types of questions posed in each layer are presented to show how Staged Appreciation relates to CSH, PSM and OR/MS respectively.

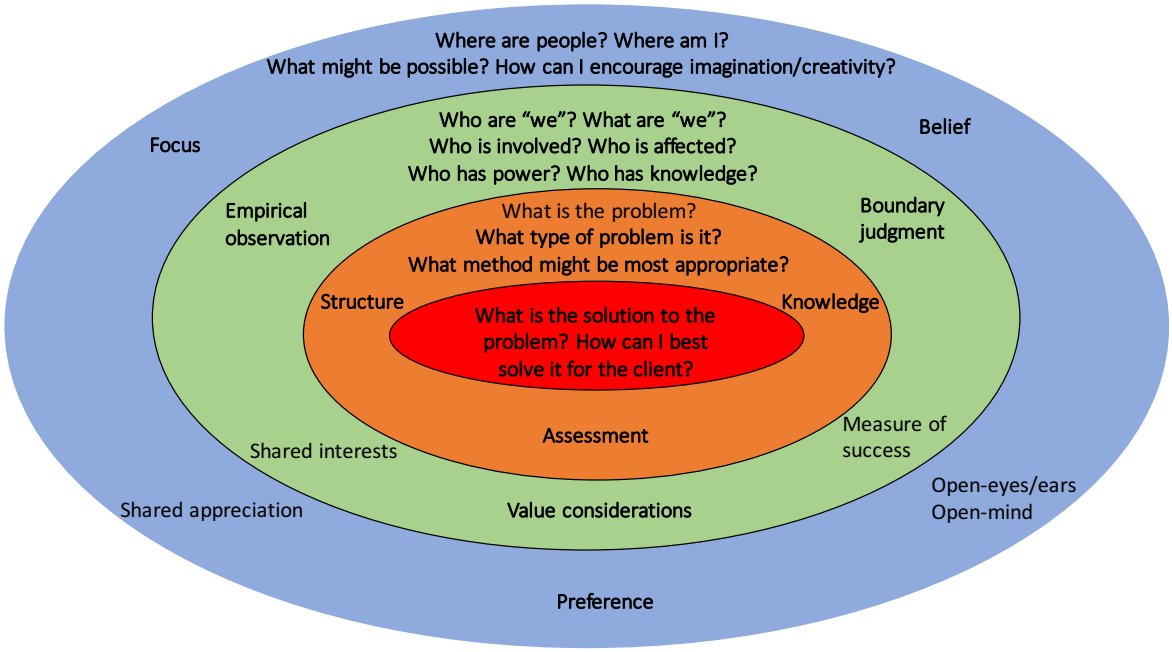

Figure 2: Staged Appreciation working through and within CSH, reflectively supporting PSM into OR/MS.

Jackson (in Jackson, 2006) also discusses Morgan's metaphors, listing them in terms of seeing "organisations as". Alternatively, and more relationally-speaking, this nested view distinguishes relational boundaries (as drawn by the ellipses in Figure 2) according to how the nature of organisation (i.e. what lies between) is being viewed or imagined when working in each of the layers. The inner layer is where OR/MS sees organisation as purposive couplings (e.g. cause-effect). The next layer is where PSM sees organisation as structural couplings. The next layer is where CSH sees organisation as cultural and political relationships. The next layer is where Staged Appreciation sees organisation as inter-personal. Staged Appreciation subsumes, and so works around and within, the other layers. Jackson (in Jackson, 2006) suggests an additional "carnival" metaphor; Staged Appreciation might suggest organisation as dance, where each person is an individual, each appreciating the dynamic relationship with opportunity for creativity and innovation.

Stakeholder Perspectives and Soft OR

Typically, designing of systems solutions is generally supported by OR advice using a well defined set of objectives, against which the system effectiveness can be measured. The OR analytical perspective provides objective measurements of effectiveness for the systems concepts under consideration. These systems concepts, however, tend to involve a diverse range of stakeholders, often each with a different perspective on value or success. So what might be 'best' or 'better' from one stakeholder's perspective may not be best or better (or even good) from another's perspective. These stakeholders are usually inter-related, and yet the nature of these inter-relationships is rarely taken to be an integral part of the problematic situation. In complex problems it may be the nature of those inter-relationships that lies at the conditional heart of a possible solution or resolution.

Checkland's Soft Systems Methodolgy (SSM) in (Checkland and Scholes, 2001) goes some way to addressing the stakeholder perspectives; however, the nature of SSM's "CATWOE" embodies a "T for Transformation" that is based on a single desired state change; also with an assumed "C for Customer" stakeholder relationship. (Seagriff and Lord, 2011) summarise the philosophy behind SSM as giving "an approach for taking a complex human situation/problem and expressing its core constituent systems in a standard way that is transparent and involves the whole client group". The need for some relational extension is captured in (Williams, 2005): "It is worth noting here that in recent

years, some associated with Critical Systems Thinking who use SSM have made two very significant changes to CATWOE; (i) They have replaced C with two concepts; B for Beneficiaries, and V for Victims (BATWOVE) (ii) B and V can include *ideas* as well as *people*. These are highly significant changes that open up new domains for SSM." In addition in CATWOE there is the "W for Weltanschaunng", which is often translated as "worldview" but the German concept embodies preference, focus and belief. It is these important W-extensions (including those of the OR analyst) that this paper addresses.

Staged Appreciation as Techne

The work to develop Staged Appreciation as a reflective framework began with a study of Shackle's approach (Shackle, 1957) to business decisions and intrinsic uncertainty about possible futures. Shackle's three functions of belief, focus and preference are woven together to capture a subjective choice perspective. Shackle's term "choose-able" has been adopted so that choice-making becomes explicit as: "Your list of choosable things has to be constructed or composed by yourself before you can choose". The concept of a choose-able is something imagined, constructed, composed and countenanced by a person to then be put forward by them as an option for decision-making or policy-making. In terms of defining strategy, choose-ables represent the imagined, deemed possible.

A person's three functions and their evolving choose-ables co-work as a dynamic whole. The premise is that, as fallible humans, it is mostly impossible to suspend our preferences and to be open about closely held beliefs. The term "preferences" refers to people's preferred tools and ways of doing things. Preferences and beliefs tend to shape the choose-ables from which a solution might be found; all of which focus interest in terms of specific indicators and measures of success. Once such a focus is set, it is difficult to remain open to different perspectives (i.e. other preferences, beliefs, foci of interest, etc) and, as importantly, to other choose-ables. This collective phenomenon is referred to by bomb disposal experts as "fatal baggage" (Sirett and Dodd, 2006), where their belief about the situation, linked to their preferred ways of working, then focused their attention away from reflecting on *what else* the critical situation might be. The question now becomes:
In what ways might options, minds and eyes remain more open?

The open-eyes/open-mind (OE/OM) matrix shown in Figure 3 was developed for the Swedish Strategic Crisis Management Unit following their seminal work (Boin, t'Hart, Stern and Sundelius, 2006). It was presented as part of Staged Apprciation to the Swedish PM Office in 2008, to reflect on surprising critical events in Stockholm when looking at counter-terrorism responses, and later for options to deal with the Assange situation. In addition, it was used in the UK and EU principally to appreciate where people are in terms of their choice-making, sense-making and purpose sharing in the context of public diplomacy. An illustrative case study looks at environmental initiatives by convening a range of stakeholders within a shared interest, and working carefully through an appreciation of 'self' and then relationships that needed to be developed. The case study is covered in detail in the chapter by Hudson and Anstead in (Welsh and Fearn, 2008).

The six stages of Staged Appreciation are illustrated through the case study as follows:

- Where people are: This addressed the positioning of people in personal, organisational and institutional terms. The people here[1] were members of the public, members of non-governmental organisations (NGOs), local authorities, trade unions, etc. Many had strongly held positions expressed through their opinions on working with others; also on other people's ways of working and of making sense of the problematic situation and its wider context. This had to be made explicit and realised, self-reflectively, by the many different people involved.
- Open-eyes/open-mind: explicitly addresses how those people, as politicians, members of groups or as individuals might be approaching their sensing and sense-making. If, for example, people are looking through the lens of their ways of being and ways of working then this, in itself, forms a large part of the problematic situation. Using the matrix to ask people where they felt they were, helps with self-reflection and willingness to see others' ways of working and rationales.
- Belief and surprise: Asking what might cause people to be surprised helps them to appreciate their own beliefs about who might be easy to collaborate with. For example: "if we had said to a number of them 'soon you will be working with such

[1] There were 330 stakeholder representatives involved in the initial defining of potential actions and then 16,900 people participated in nineteen regional meetings, in which thirty national councils offered views.

and such' they would not have believed it…. Normally critical, NGO and media voices were openly surprised" (see[2] p151 in Welsh and Fearn, 2008);

- Choice-making and choose-ables: Asking explicitly about what people felt were their possible and impossible options for future ways forward helps them to appreciate the limits they were putting on future choices and then to understand that working with others could open-up more options. This important activity of choice-making is an essential key to open-up new working relationships for co-creating ways forward: "to identify and design solutions to their shared problems, exploiting the diversity by their multiple perspectives, experiences, skills and creativity" (see p148 in Welsh and Fearn, 2008);
- Focus and preference: are intricately related to belief and choose-ables and if all of these can be openly appreciated then "where people are" (especially in terms of open-eyes and open-mind) can be addressed as part of the problem situation. For example: "to identify and understand the extent of their shared interests and potential for joint action…within an overall plan in order to deliver agreed outcomes" (see p148 in Welsh and Fearn, 2008);
- Multi-perspectives: can now be more fully and broadly appreciated with a richer understanding of the diverse range of people's views, pre-positioning and rationales for choose-ables: "The consultation managed to convert this shared interest into a **shared appreciation that working together could lead to concrete results,** and was more likely to do so than each party pursuing its own agenda in isolation." (see p152 in Welsh and Fearn, 2008).

Staged Appreciation and the OE/OM matrix provides a reflective framework that promotes not just knowledge sharing but also shared appreciation of relative feeling, to put focus on where people are, cognitively and epistemologically, in terms of their sensing, sense-making, shared interest and choice-making. This collaborative creating of contextual and relational conditions for such shared appreciation of interests and

[2] In more detail: "Normally critical NGO and media voices were openly surprised that agreement had been reached on sensitive issues such as transport (restrictions on building of highways or airports, further development of the rail network), building (homeowners to be required by law to make homes energy efficient and given funding to do so), energy (the development of renewable energy to be prioritised over that of other energy sources) and agriculture (organic farming to increase from 2% of cultivated land to 20%; the use of pesticides to be reduced by 50%; the growing of GM organisms to cease)."

knowledge can be linked to Nonaka's concept of "Ba" (Nonaka, Toyama and Konno, 2000).

The positioning of people (including the OR analyst) in the OE/OM matrix (see Figure 3) is a key reflective stage. The objective problem-solving position is in the bottom-left quadrant of the matrix: closed-eyes and closed-mind (CE/CM). Here the focus is fixed onto pre-selected indicators that serve to provide evidence to support the held hypothesis and beliefs about the world (i.e. the mental models). This evidenced form of analysis is essential best practice for problem-solving. The bottom-right, open-eyes/closed-mind (OE/CM) quadrant represents an 'out of model' surprising event, which opens the eyes but then, because of the closed-mind, is often ignored or dismissed as a freak event. Such "black swan" events described in (Taleb, 2008) signal that people's extant 'belief' models need to be questioned and adapted. This mind-opening is challenging when people's professional reputations are at stake, and often 'black swans' are readily dismissed as white swans that have flown through a sooty chimney, so the "all swans are white" model still holds, unquestioned. If minds are opened by the opening of eyes then people can be open to imagining new, alternative ways forward. So for people to be able to be open-eyed and open-minded (OE/OM) they must be open to seeing others' perspectives and also to appreciating other people's choose-ables.

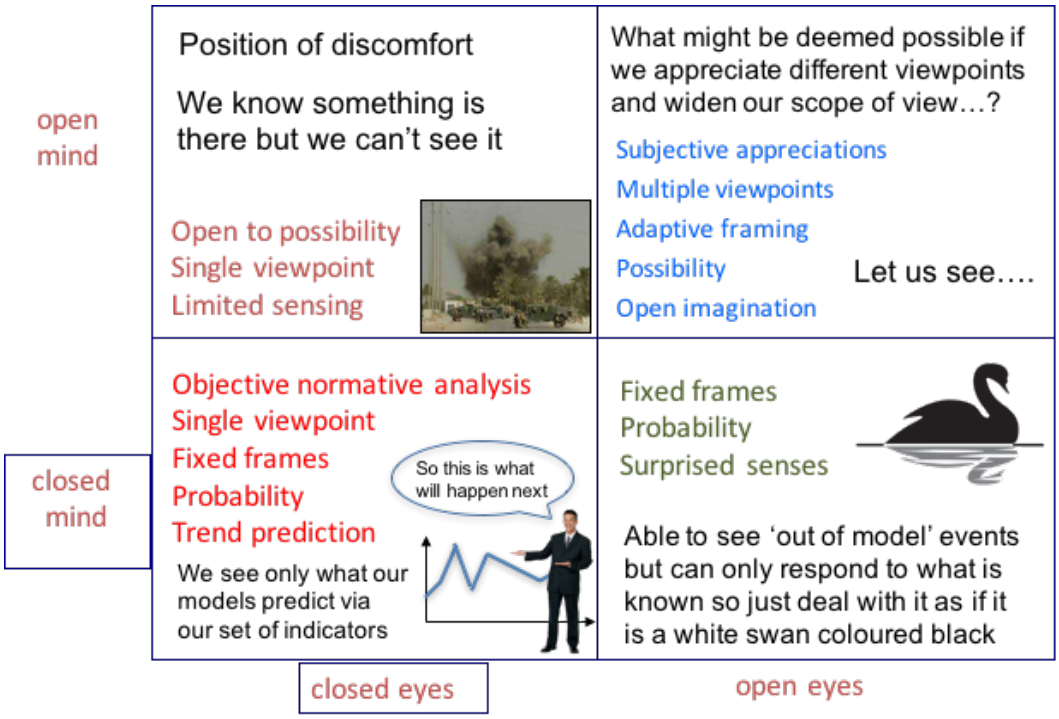

Figure 3: Open-eyes/open-mind matrix to appreciate where people are in terms of sensing and sense-making (Dodd, Alston and Stamp, 2010).

The remaining top-left (OM/CE) quadrant of the matrix is a position of discomfort, when one's mind is open to possibilities (i.e. what might be) yet there is no way of sensing the signals or events. People in OM/CE are prepared for events, and are often working on new ways of sensing with wider awareness more generally; however, this will be disquieting if the institution in which they work has a 'mind' that is closed and imposes closed-eyes policy; as discussed in relation to health workers in (Menzies-Lyth, 1988).

Generally there are two factors associated with closing of minds, eyes and choose-ables:

- Constraints on the means available (e.g. resources, time, etc);
- Restraints on the ways available (e.g. rules, procedures, cultural taboos, etc).

It may therefore be helpful, in the first instance, to make explicit the reasons for these constraints and restraints. The work needed to open up the choose-ables funnel as shown in Figure 4 is essential (but hard) work. This is the key to opening minds and eyes. If the presumed constraints can be made explicit, then it may loosen the presumed restraints. This then provides the cognitive and emotional space for imagination (both futures and options) and different ways of seeing; potentially leading to innovative ways forward.

Specifically, here the 'deeming possible' is linked to people's attitudes to constraints and restraints, so it is a way to capture the essence of strategy as shaping potential for a more openly desired pattern to events, via the dynamic medium of choose-ables construction.

Keeping time and option-space open provides the necessary conditions for OM/OE; however that is not sufficient. The Weltanschauungen also need to be made explicit if at all possible. So people will need support as they are being asked to be explicit about their preferences and beliefs, that are shaping and forming their measures and indicators of success (personal and organisational).

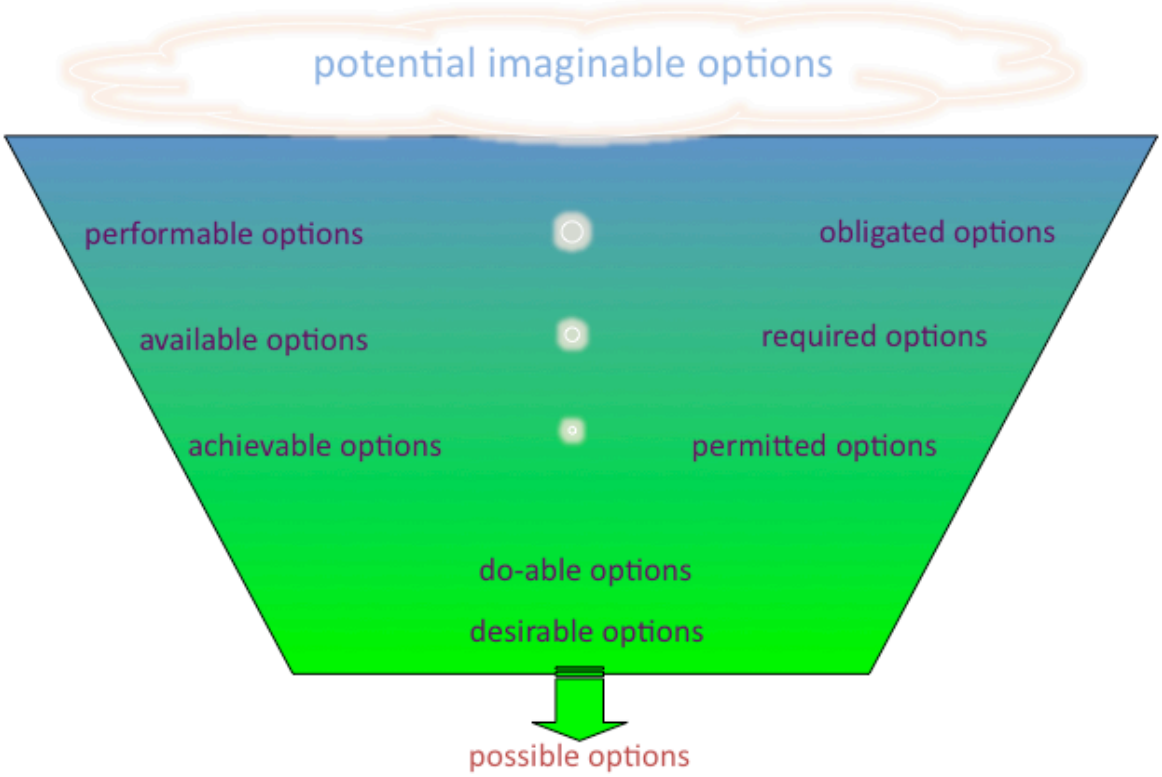

Figure 4: Options funnel to consider "imagined deemed possible" (adapted from Bradshaw, Feltovitch, Jung, Kulkarni, Taysom and Uszok, 2004)

One approach to eliciting preferences perhaps is through Appreciative Inquiry (Cooperrider and Srivastva, 1987); for example, asking people what is working well for them at the moment (or what has worked well in the past) reveals not only what they consider to be 'good' but also what matters to them, revealing the conditions that make the 'good' possible. Shackle refers to a "surprise function" as the inverse of a person's belief 'function'; so asking "what might surprise you if it happened?" and "how much would that surprise you?" helps to reveal the shape and position of tacit beliefs and mental models. All of this is covered through Staged Appreciation.

The paper now selects two techniques in support of OR analysis and problem synthesis.

There are many other techniques for sharing knowledge and understanding of the problem with others involved in the problem (Monks, Robinson and Kotiadis, 2016). The techniques selected draw out different perspectives and also support a synthesis of those perspectives set against a broader view of the problem-solution context. All of this helps to guard against solving the wrong problem; also it helps to work towards a more robust

and settled, more sustainable, relationship-based resolution rather than the single-point "best" short-term, action-based solution.

Suggested Techniques

Two selected techniques are suggested here as they specifically address (i) multiple stakeholder perspectives and (ii) opening out to alternative options. There are many other techniques that are currently in use (Heuer and Randolph, 2015). Each technique provides a subtly different way to support open conversations and of sharing of understanding.

Adopting a multi-perspective approach

The 'pig' model described in (Morgan, 1997) helps people to look at a problem from different perspectives. The first conversation that needs to take place is around what seems to be the central issue of the problematic situation (i.e. the key system of interest). Once this has been agreed (at least to begin with) this issue is drawn centrally as the 'pig' of the problem. The stakeholder persectives can then be developed based on what the 'pig' means to each stakeholder. So for instance, a pig farmer might see a pig as an animal and also as income; a child reading a story book might see a pig as a cute curly-tailed friend. It is on this basis that the stakeholder perspectives (including the analyst's own view) are developed based on that central issue. Quite often it may only be possible to guess or imagine how a particular stakeholder might view the central issue; this in itself is an important unknown (and a CE/CM signal), especially if this is a key stakeholder. Use of organisational metaphor is also important here as it draws out the nature of couplings and inter-relationships (e.g. people talking about levers and mechanisms).

Figure 5 shows an illustrative 'pig' diagram that relates to a potential environmental policy about a restricting airport expansion in rural areas.

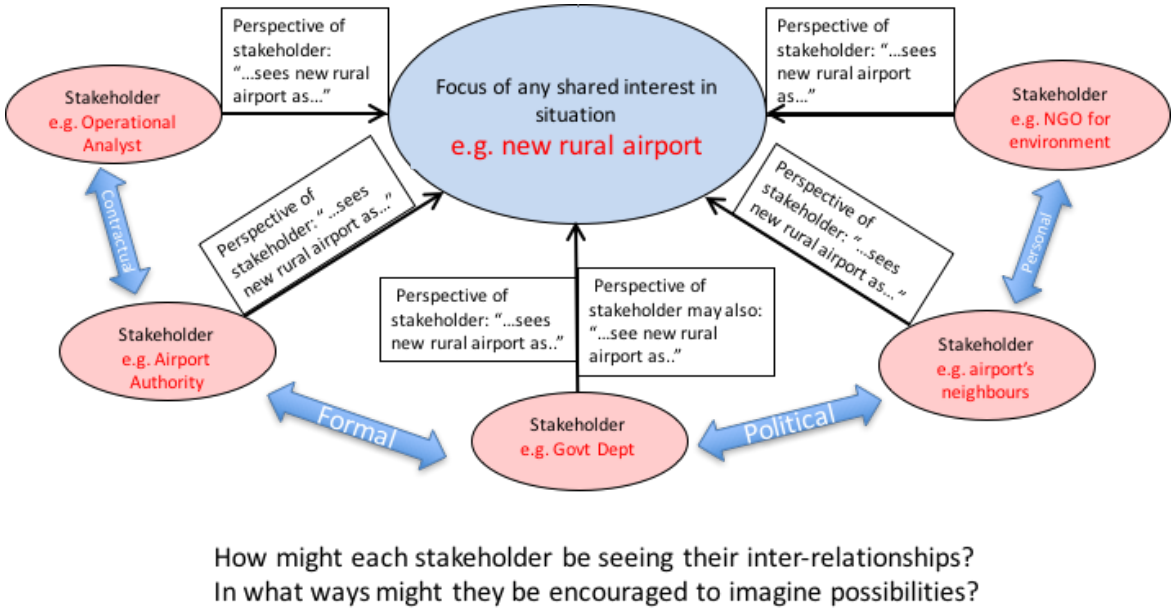

Figure 5: Illustrative example of a pig diagram relating to potential for restriction on rural airports.

This can be taken a stage further into a multi-perspective approach to support "what if?" analysis for a proposed policy option or an operational decision (Alston and Dodd, 2009). For example, if one preferred option is to restrict new rural airport development then "new rural airport" could be the initial central issue (i.e. the 'pig'). The multi-perpsective analysis of the 'pig' then considers the following questions:

- What really matters to each of the stakeholders regarding this central issue?
  (Form this as a line of perspective (e.g. commercial, environmental) for each key stakeholder.)

- Where people are: how might each stakeholder define their current position on that line of perspective?

- Where might they prefer to be positioned in relation to the policy option?

- What would seem to be making *their* appreciation of *their* position better or worse?

- What if anything might you/they do to affect any aspects of the situation?

The final question then leads into a more open exploration of the possible policy options. This may need to be opened-up to explore whether the proposed option is a solution to an

ill-formed, closely bounded problem, and may need an initial focus on shaping relationships.

Ladder of Abstraction

The Ladder of Abstraction technique (Isaksen, Dorval and Treffinger, 2010) takes the proposed policy option and explores the space around it in terms of alternatives and also encouraging alternative ways of thinking about the situation; in particular, finding a possible shared purpose or new shared interest. The ladder of abstraction builds from Checkland's PQR analysis (Checkland and Winter, 2005): why? what? how? It explores the contextual alternatives: "why else?", "what else?' and "how else?" based around the opening question: "In what ways might….?". Importantly the open questioning must agree on a problem owner, an active verb and a declared objective; so, this relates to any CSH thinking that may have been done. For example, if there is a proposed policy to restrict new rural airport development then the opening question would be: In what ways might the government restrict new rural airports?

Figure 6 illustrates the starting state of a ladder of abstraction from which it can be expanded, upwards and outwards, as necesssary to explore a whole range of possibilities. The technique helps analysts to convene with problem owners and other stakeholders to work rigorously yet creatively through their problem space. In many problematic situations there is rarely one problem owner; indeed there may be no single obvious 'owner'. Often the problem has been situated in a solution space, which then tends to dictate the analysis. This brings power relationships to the fore, as one preferred solution may be being pushed. In these situations, power relationships form an important part of the intricacy and need to be made an explicit part of the problematic situation.

The two techniques described have been selected and suggested because they directly support two of the key stages in Staged Appreciation: reflective multiple perspectives and choice-making. There are many other techniques that would be appropriate here.

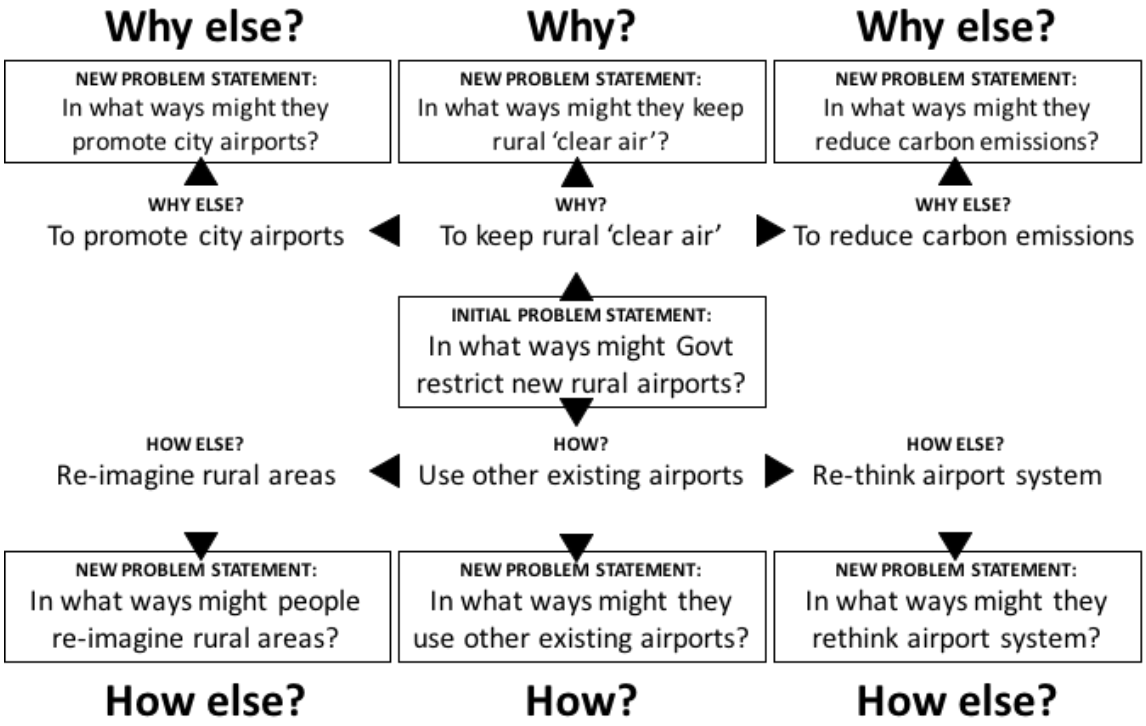

Figure 6: Illustrative example of Ladder of Abstraction adapted from (Isaksen, Dorval and Treffinger, 2011)

Discussion

It is the following two aspects of problem understanding and formulation that Staged Appreciation is addressing: first, that all problems involve people (including the analyst as being a person); and second, that people bring with them their personal and professional preferences and relationships. It can be argued that OR practice already has methods and approaches for problem formulation and critical analysis; for example, CSH in support of boundary critique and multi-perspectives on value; also System of Systems Methodology (SOSM) (Jackson, 2003) for matching method to problem-situation, respectively. This paper suggests that Staged Appreciation works around and within, so complementing and supporting, use of these methods. It also extends CSH to further support reflective practice, by asking those doing the analysis to appreciate their own OE/OM position on the issues/policies at stake. This is important for PSM and SOSM because the analyst and problem structurer need to appreciate their position in the situation. It acknowledges that eliciting people's beliefs is asking for almost impossible honesty and openness; however, people are more able to be open about what might surprise them if it were to happen, and

also *why* they would be surprised. This can help to lead into more open discussion about where people are focusing their attention, to appreciate any narrow-ness of focus.

Referring back to Figure 2, CSH addresses values whereas Staged Appreciation acknowledges people's personal preferences and instituional preoccupations, which then become entwined with focus, sense-making and choice-making. So Staged Appreciation goes further into the personal spaces "where people are" and as such it can be both a preparation for CSH-supported conversations and can act as an aid when using CSH as an approach. The shared appreciation by those involved can work towards those affected becoming involved through key people appreciating new shared interests. Having Staged Appreciation working around and within CSH, SOSM, PSM and OR/MS helps to shape relationships and create 'choose-able' conditions for realising shared interests, sustaining more open conditions for shared appreciation.

Staged Appreciation is proposed only as a guiding check-list to help to build techne for reflective practice when analysts are using systems-based techniques; and when using approaches, such as CSH, when looking at boundary issues and multiple perspectives; also, when selecting appropriate methods through SOSM. Indeed, it is this aspect of selection of analysis method that may need to be mindful of Staged Appreciation. This is the main theme of (Wright, 2013) where the key question is: "What reliable approach or method can be used to guide the selection of a suitable methodology or defensible combination of methodologies to help understand and resolve a complex problem situation?". The thesis points to the work of (Mingers and White, 2010) to describe how the SOSM approach has moved more towards combining systems methods, "[it] eventually moved from the question of selecting a single method, to recognising the value of combining together different methods, not just soft but especially employing both hard and soft methods together. This is known as multimethodology or coherent pluralism." It is the challenge of coherent pluralism that Staged Appreciation helps to address by drawing out the deep personal and relational bases that underlie people's purpose(s).

The illustrative case study shows that if those working to convene disparate people are able to work with and through the six themes of Staged Appreciation as a supporting trellis for developing their reflective practice, then (see p152 in Welsh and Fearn, 2008):

"convening all relevant stakeholders in an explicitly open forum helped to bring to the fore a sense of underlying shared interests…The consultation managed to convert this shared interest into a shared appreciation that working together could lead to concrete results."

The soft systems techniques and the skilled practices of PSM and SOSM, to identify the problem and to select appropriate methods respectively, always remain at the centre of reflective practice. If they can be guided by Staged Appreciation, then that strengthens those reflective practices and supports CSH, sustaining the emphasis on people and relationships. Given that the concept of choose-ables represents the imagined deemed possible, Staged Appreciation provides sustained conditions for the 'deeming' of new, innovative ways of working together. Where convening is deemed not to be possible, then CSH provides a supporting framework, with the Staged Appreciation 'check-list' being kept in mind for seeing any relational opportunities that may arise for collaboration.

Conclusion

Staged Appreciation acts as a reflective framework to provide a working check-list for guidance through a socially and personally complex problematic situation. Such a form of techne is arguably needed to complement OR analytical skills and competencies for self-reflective application of techniques. "Where people are" stands proud in the check-list because it is asking analysts to appreciate where people, including themselves, stand in terms of how they might be seeing the problem and making sense of their relationships. It also asks the analyst where they stand in relation to others; in particular, their clients.

OR analysts' skills and competencies lie in finding solutions to challenging problems. In socially complex situations it may not be possible to find a solution; it may only be possible to work towards a resolution. Staged Appreciation helps people to appreciate that relational conditions may need to be worked on. This could involve elevating the personal aspects, or re-focusing people to appreciate where they are in relation to each other, in order to see if conditions can be reached for agreeing shared interest (or purpose) through shared appreciation and for re-shaping relationships. An analyst may have to put their reputation as a problem-solver to one side and reflect on the need for further abstraction and a widening of the client-analyst and stakeholder-stakeholder relationships. Because

Staged Appreciation is not a method, its limitations lie in the challenges posed by the people involved in the situation and in the natures of their relationships. All that Staged Appreciation is trying to do, as a guiding framework, is to keep people mindful of that.

The selected Systems Thinking techniques are presented simply as an illustrative example of how they can support analysis through this process of open appreciation. There is a plethora of techniques to choose from. These systemic ways of working are not entirely new (Mingers and Rosenhead, 2004). Systems Thinking techniques, guided by Staged Appreciation, supported by Shackle's work and Vickers' principles, and as embodied more recently by Nonaka's approach, together appear to add an insightful new dimension to knowledge sharing for understanding and reflecting upon the intricacies involved in socially complex situations.

It may be that analysts would prefer to develop their own techne 'check list' as a reflective 'handrail' to openness, and they may choose to use different techniques. What matters is that OR analysts begin to work more reflectively (Argyris and Schön, 1996) and support people in thinking more openly as we engage in the socially complex world.

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Title: Choice-making and Choose-ables: making decision agents more human and choosy

Author: Lorraine Dodd

Corresponding author address:

Cranfield University, Decision and Information Management Group

Room MH103b, Defence Academy of the UK, Shrivenham, Wiltshire SN8 7LA, UK

Email address:

L.dodd@cranfield.ac.uk

Telephone: +44 (0) 1793 314576

ORCHID ref: 0000-0002-0282-1633

Abstract

This paper discusses concepts that might shape, extend, limit or re-focus an agent's set of options, that can then be thought of as that particular agent's *potential* in terms of their ways forward and degrees of freedom. Because there is no unambiguous word that conveys the meaning of this higher-order concept of choice-making, the term "choose-able" has been adopted in order to distinguish it from the usual decision concepts known as choice or option. An agent's choose-ables are defined as the imagined deemed possible ways forward, that the agent has to construct, compose or create before they can choose. The central concept of a choose-able is a very powerful one if only it could be surfaced and made explicit. It is often only possible to make inferences about the nature of choose-ables after observing the actions taken once a choice has been made. Drama Theory formally develops this kind of inferencing and provided a foundation for this paper as it explores the relational realms of options. The paper presents a funnelling construct and then draws together Catastrophe Theory and Culture Theory to offer new ways of analysing the shaping effects of relational contexts on an agent's choose-ables, that then act as a medium through which agents are drawn to make choices and carry out observable actions. The strength of the combination of the theories lies in their descriptive power of subjective, relational concepts that hitherto have tended to remain hidden and tacit.

Keywords: Decision options; Choice; Catastrophe Theory; Culture Theory.

MSC codes: 91C99; 91B14

1. Introduction to choice-making and choose-ables

The subject of agent-based decision-making spans many areas of research, simulation and modelling; as covered in the recent comprehensive survey, by Balke and Gilbert (2014), that compares and contrasts architectural frameworks for modelling decision agent processes. These agent-based decision frameworks deal principally with modelling an agent's course of action selection from a given set of options. This paper does not aim to extend those existing architectural frameworks for selection of "a choice" from a set of options[1]. This paper deals with the contextual factors involved in composing an agent's set of options in the first place.

This paper discusses concepts that might shape, extend, limit or re-focus an agent's set of options, that can then be thought of as that particular agent's *potential* in terms of their ways forward and degrees of freedom. Because there is no unambiguous word that conveys the meaning of this higher-order concept of option-making or choice-making[2], the term "choose-able" has been adopted in order to distinguish it from the usual decision concepts known as choice or option. The term "choose-able" is introduced because there does not seem to be a formal name for the concept of a choose-able. It has been adopted from work by Shackle (1976): "Your list of choosable things has to be constructed or composed by yourself before you can choose". An agent's choose-ables are defined as the imagined deemed possible ways forward, that the agent has to construct, compose or create before they can choose.

It is an exploration of why a decision agent's circumstances and relational conditioning might shape or directly affect their choose-ables. The central question being addressed is: what might be intrinsically or extrinsically affecting an agent's degree of decision freedom? So this paper is about understanding conditions for the shaping of choose-ables, from which decisive consequences may (or may not) then flow. It is trying to reflect a more analogue approach to thinking about how an agent's potential for choice might be scoped or broadened. The approach works through from contextual, subjective conditions to consequential potential, via a notional 'funnelling' that works to either limit or open-up an agent's choose-ables.

Choose-ables cover the possible ways forward that any agent:

- Can conceive of (or imagine);
- Would countenance as being one of their choose-ables (e.g. within their moral code[3]);
- Feel are open to them for choice (e.g. given their relational circumstances);
- Feel they are obliged to consider;
- Feel competent to consider;
- Feel they are barred from considering (e.g. social taboos).

There are strong similarities with the concept of affordance (Bradshaw 2004) in that choose-ables describe the subjective contextual nature of the opportunities for choice-making and the 'wiggle room' for consideration of potential ways forward. Affordances are properties of the context taken relative to any person or agent (Wells 2002) and, as such, they do not explicitly define that agent's constraints or desires, being more about perception of environment[4] inviting an active response. Affordances pertain to the context but are relative to and subject to what that context offers, opens-up

[1] The paper remains agnostic about operational feasibility and desirability at the time of option selection, which tends to be the usual focus of agent decision-making architectures.

[2] Choice-making is used here to differentiate it from decision-making and decision-taking. This paper is not about rationales for decision-taking, which lie in the realms of decision theory and game theory and where there tends to be a pre-defined set of options; each with a likelihood of outcome or pay-off.

[3] There are deeper philosophical foundations that underlie much of this paper (Arendt 1982).

[4] For more detail see Klugl F (2015) Affordance-based Interaction Design for Agent-based Simulation Models. In Multi-Agent Systems, Bulling, N. (Ed) (2015) Proceedings of the 12th European Conference on Multi-Agent Systems (EUMAS) Prague, December 2014.

or closes off, perceptually as well as operationally (Gibson 1979), for that decision agent in their current personal circumstances. This does not explicitly include the agent's capabilities in terms of what might be predicted to be probable outcomes of decisions[5], both of which will further affect an agent's ultimate choice of option. An agent's appreciation of how difficult or impossible it is to predict is related to their ability to look at context[6]. That difficulty or impossibility to predict tends to increase with complexity and intricacy of context.

In essence, the paper proposes conceptual extensions into higher orders of decision agility (Dodd and Markham 2013) and higher levels of adaptation (Grisogono 2004) to reason about an agent's potential or degrees of freedom for choice. The proposed conceptual frameworks are underpinned by developmental theories drawn from the mathematics of discontinuity (Zeeman 1977), subjective economics (Shackle 1976) and from culture theory studies (Douglas 2008). The aim is to address how levels of adaptation might be extended within decision agent frameworks to capture how and why agents might limit or extend their choose-ables (as listed previously).

This paper provides a framework for reasoning why agents might be subjectively scoping their focused set of options and how the ever-changing context is working to shape their choose-ables. So it offers a way to address (and maybe eventually to encode), as a whole, what might subjectively scope, shape, constrain, restrain, open-up, extend or enhance an agent's choose-ables.

The nearest there is to a collective concept might be referred to as an agent's portfolio of choices that are deemed to be OK by them and for them to choose from. The important point being that the nature of that deeming of 'OK-ness' is temporally subjective; that is, according to that agent (or agency) at that time and in terms of their particular circumstances and concept of time span. This collective concept can also relate to a person, group or an agency (Sylvan and Voss 1998): "Previous studies of foreign policy decision making have largely focused on the choice among specified options rather than the prior question of how the options were specified in the first place."

This requires a step back to explore what might be happening in that agent's relational, cultural, 'personal', organizational and temporal contexts. This further requires access to an agent's implicit, trust-based, rationale for what they might (or might not) be open to considering as one of their choose-ables, given their current circumstances and 'personal' experience to date. For example, a vegetarian 'agent', in their everyday circumstances, would not countenance having "eat meat" as one of their choose-ables; however, if their circumstance were one of extreme hunger and they were being kindly and generously offered meat stew, then they may extend the scope of their choose-ables temporarily to include "eat meat". The strength of their cultural relationships and personal positioning plays a large part too, as described by Douglas (2008). For example, if they are tied-in to a patriarchal grid structure or if they choose to conform to the values of a social group then their degree of autonomy in choice-making will be relatively shaped or biased.

Choose-ables are, therefore, subjective and personal and tend to be shaped, limited and/or opened-up according not only to an agent's context but also to the extent and nature of their awareness of that context. This contextual framing can also extend the concept of a choose-able to be not only about active ways forward (e.g. eating meat), but also ways of making sense of situations (e.g. interpreting a scene as A or B), of where to place their attention (e.g. focused or wide attention[7]), or what to believe, whose preferences to take account of, etc. This can be extended further if we are to consider decision agents (e.g. agents representing managers) whose choose-ables might be organisational (e.g. empowerment of others) or ways to shape relationships (e.g. building of governance relationships).

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[5] In terms of 'Ways, Means, Ends' the focus here is firmly on the scope and nature of the ways forward and is not directly concerned with the available means or the desired operational ends.

[6] Referred to by Harvard's Nohria, Mayo and Khanna as "contextual intelligence" (see Khanna 2014).

[7] "The second way of perceiving seemed to occur when the questioning purposes were held in leash. Then, since one wanted nothing, there was no need to select one item to look at rather than another, so it became possible to look at the whole at once." (Milner 1986, p106)

The basis for a previous "Theory of Choice" paper (Dodd 2011) is that choose-ables tend to frame the ways in which agents may be able to sense, feel, interpret, discern, assess, adapt and act in their world (Dodd et al 2008). In turn, all of these are shaped and conditioned by the nature and scope of the ways forward that appear to be open to them at the time of need for choice-making and decision-making. For example, if an agent has only one way forward then the situation may need to be seen and framed to fit that one way forward to provide the comfort of knowing and of having "the solution to the problem"; as in: if I only have a hammer then every situation for me becomes a nail to be struck. For example, western governments, bound by accountability and strict legal scrutiny, are often limited to only one choose-able, such as imposing sanctions. Their focus on sanctions then tends to limit the way in which they see and make sense of the situation. This naturally suggests that the influences flow both ways between the sensing or sense-making and the choose-ables that are seemingly open for choice; therefore, having a closed mind and firmly focused eyes tends to close-off options for choice; however, not being open to more options for choice tends towards finding comfort in one's closed mind and ears and focused eyes.

The central concept of a choose-able is a very powerful one if it can be surfaced and made explicit. The other related concept is, as previously mentioned, "affordance", which is taken here to be a relation between a context (of agency and people) and an agent (Bradshaw 2003) that affords the opportunity for that agent to perform a decisive action. The idea of affordance is relatively new[8] and it is essentially a concept of design, or policy, giving way (i.e. offering a way forward) to subjective choice. The idea of affordance has been developed further, as a relation between an agent and its context, in the domain of human-machine cognition, as in Bradshaw (2004a). Figure 1 depicts the relationship between the extent of an agent's imaginable 'wiggle room' for choice[9] and that bounded by a policy-based structure or design; the relevant area here is the area marked "wiggling the wiggle-room" as this is a simple representation of the imagined deemed possible (i.e. choose-ables).

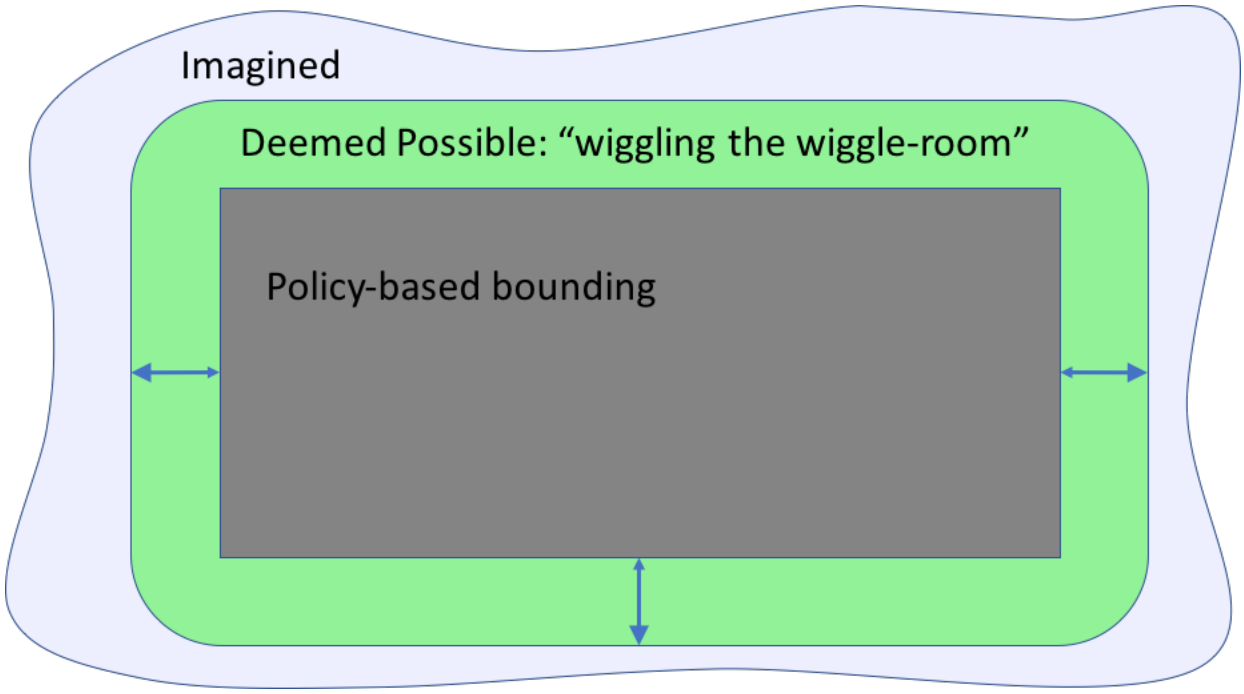

Figure 1: An agent wiggling its wiggle room (Bradshaw (2004b))

[8] James Gibson (see Gibson (1977)) and Donald Norman (see Norman (1999)) are two of the main originators of the idea. As an example, a door with a pull handle would suggest that it should be pulled and not pushed, so the handle holds an affordance for pulling.

[9] "An agent's 'wiggle room' consists of its set of performable actions in a given context, while the policy-based bounds that people impose on that wiggle room define a smaller region of trusted operation. Capabilities for adjustable autonomy support the modification of these bounds at runtime in order to adapt to changing conditions." Bradshaw (2004b).

These intangible, relational concepts are difficult to make explicit. Agents (also agencies and people) do not openly display or make explicit their choose-ables and they may not even be explicitly aware of them. It is only possible to make inferences about the nature of choose-ables after observing the actions taken once a choice has been made. For instance, if we see a person carrying out an extreme form of action then we could infer from that chosen action that their choose-ables extend further than the scope of the majority. Drama Theory[10] (Bennett et al 2001) formally develops this kind of inferencing and provides a foundation for this paper as it begins to explore the relational realms of decision options. Drama Theory helps analysts to reason about the contextual shaping of a decision agent's openness and willingness to imagine, countenance or consider an option for choice in order that it may then be deemed worthy (or not) of becoming one of their choices for action selection[11], finally resulting in observed behaviour.

2. Extending agent frameworks: capturing the context

Shackle (1976) introduced the concept of choose-ables in terms of: "the imagined, deemed possible". His mathematical notation is unusually subjective, which makes for a challenging read for those who require "x" to be an objective variable. Shackle's three functions represent personal preference, belief and focus (i.e. of attention or interest). These functions are composed to shape decision conditions and consequences, where time is not constrained to be objectively chronological (i.e. chronos time) but can be interpreted as being of subjective opportunity (i.e. timing or kairos time in Dodd and Markham (2012)).

This exploration of Shackle's (1976) concept of choose-ables, proposes a practical construct, which can then be abstracted into frameworks that refer to non-linear mathematics and culture theory, in order to capture the context in relation to subjective choice-making.

The proposed practical constructs are based on a triangular foundation that asks:

What might be shaping an agent's choose-ables?

Essentially there is a sense of 'three-ness' running through the narrative of this paper. Shackle's three integrated functions of belief, preference and focus relate more to an agent's sensing and sense-making for choice-making. There are other foundational theories that are triangular in nature, yet relate more to choice-making for action-taking; either for active, decisive or adaptive action.

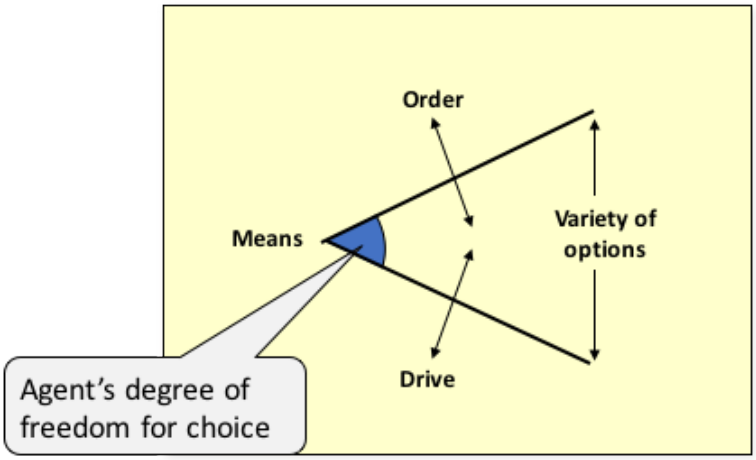

Figure 2: Agent's drive and adherence to order relating to variety of options.

[10] Drama Theory is referred to here rather than "Confrontation Analysis" as Drama Theory opens up imagination and inquiry about possible and plausible hidden subjective motives and (often unknowable) relational states.
[11] These are referred to as "cards" in Confrontation Analysis (see Howard (1999)).

Figure 2 gives a representation of Turing's association of the concepts of (i) drive (or motivation) and (ii) need for order, with (iii) a variety of stable options. If an agent's adherence to policy-based systems of order (e.g. laws or norms) is strong and their drive to act differently is low then their variety of options will tend to be relatively small. Turing's foundational trinity is more in the spirit of morphogenesis[12] as it relates to an on-going 'bandwidth' of adaptive capability; however, Turing's conceptualisation of variety of options for choice as a bandwidth of adaptive capability is relevant to the concept of 'wiggle-room' in terms of extended degrees of affordance, as discussed previously.

Similarly, Clausewitz's trinity in his book "On War" (first published in 1832 but see Clausewitz (1993)), captures an agent's freedom for choice being dependent on (i) an agent's drive towards action; (ii) an agent's subordination to instruments of policy or power; (iii) an agent's relationship with context. The Clausewitz trinity is often interpreted simply as the three terms: agency, governance and action; however, Clausewitz described his trinity as an interactive set of three basic dominant *tendencies* that drive the events of war, composed of: "primordial violence, hatred, and hostility; its element of subordination as an instrument of policy; and the play of chance within which the creative spirit is free to roam." This Clausewitzian view suggests that the choose-ables represent choice-based 'ends' in the form of aiming for an inherent active capability; for instance, we can then say that if a person is given a deadly weapon and the training to use it, also is bound by subordination to political orders, and has the will to use the weapon in specific relational contexts, then a person is capable of political killing.

The practical funnelling construct holds that choose-ables can be related to capacities or competences, moderated by will and motivation (e.g. the highly motivated agents are more likely to adapt and extend their choose-ables) and the degree to which they might be in accordance with policy, rules and regulatory laws (i.e. that are felt necessary to abide by). The broadening or narrowing of the funnel (see Figure 3) represents the opening-up, closing-off, trading-in or trading-out of choose-ables and begins to bring to light the potential openings and constraints due to the relational context of the agent (i.e. in terms of structural couplings). The graded colouring from blue to green within the funneling construct refers to the agent's "deeming" of the imagined to the possible.

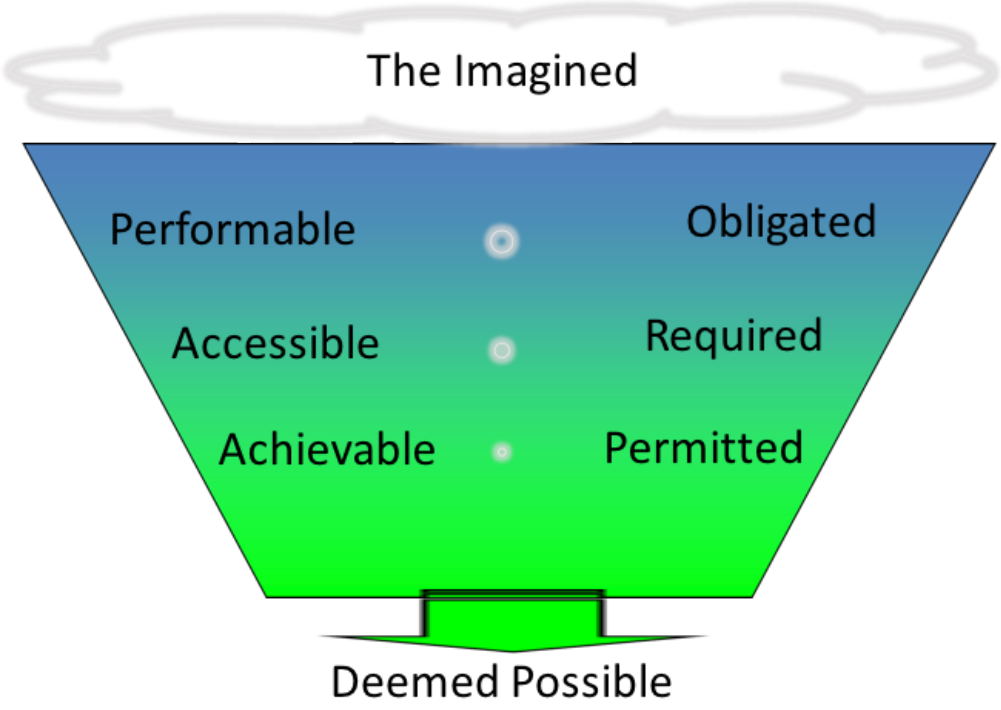

Figure 3: A triangular funnelling construct to represent shaping of choose-ables (adapted after Bradshaw (2004))

[12] Interpreted from discussions with Dr David Marsay on variety of stable states based around Turing AM (1952) The Chemical Basis of Morphogenesis. Philosophical Transactions of the Royal Society of London 237(641).

A useful question regarding the contextual state of an agent could be: "Where might the agent stand, relationally speaking?" (where this includes their position relative to power and authority, for example). This could be followed by: "What might the agent be trying to achieve? and what might they believe they need to do (and might be capable of doing or not doing) to achieve that?" Many assumptions will have to be made to answer these questions; however, a useful indicator that our assumptions may be open to further question would be if something arouses surprise.

It is the nature of the relationship between the context and the agent that is important. If an agent is socially open to working with others' preferences and considering others' perspectives, then choose-ables will be more open to including others' options and also open to finding compromises that are OK for all concerned[13]. The agents' choice-making then is more about finding a resolution that is acceptable to all concerned[14] than finding a solution that is 'best' according to the agent's preference.

This also applies to people in today's society, with ever tightening norms and demands to deliver targets. Choose-ables are often traded-out due to restraints and constraints imposed by the institutional or organizational context. This, though degrees of contextual intelligence, may then be tempered by one's outlook to the wider scope of relationships and/or immediate needs. For example, one may be tempted to consider including a choose-able that goes outside the norms or rules, if it could open up useful relationships. The scope of choose-ables can often be most severely constrained by institutional norms and rules; so there is conformance and compliance to keep to those choose-ables that are consistent and 'normal'. The Greek term phronesis, or practical wisdom, can be described as knowing when to judge which rules to break and by how far.

This mix of contextual and textual constraints and restraints provides a rich texture[15] through which to study what is happening at the boundaries between the context and the text of the choose-ables. It is across this boundary that the text describing the set of choose-ables is shaped by the context, through an agent trading-in or trading-out their choose-ables (according to the changing context, which might be a kind of dynamic conditional landscape that shapes consequential actions through a medium of choose-ables). A helpful matrix is provided in Christensson (2008) that works through three staged transformations to address the how, what and why actions may be considered in a collective context.

There is also the notion of subtext, which is covered in more depth in Drama Theory and Confrontation Analysis, when an actor's choose-ables *are* left openly 'on the table' (or can be left hanging ambiguously) in order to threaten, coerce and persuade others. For example: "We are keeping the option of nuclear strike on the table". This aspect of subtext will not be covered here as the focus is on general context for shaping choose-ables rather than what can be consciously used to undermine or influence others' choices; although there are strong links between the two.

3. Bringing context to bear through Culture Theory

Culture Theory offers a relational view of agents in context. Thompson (2008), based on Douglas (2008), suggests four relational states (see Figure 4): hierarchist, individualist, egalitarian and fatalist. Each appears to have a different characteristic choice function, which could be used to represent an agent's choice-making when in different relational contexts. For instance, when in a hierarchist state the agent tends to subscribe strongly to group norms and also to a defined grid structure (e.g. a military culture) so tends to be trying to find a workable balance across a hierarchy of purpose, aiming to take other agent's preferences and perspectives into account to find a balanced resolution; whereas when in the individualist state, the agent tends to work to their own preference and perspective, being only

[13] These can be categorised (as at University of Groningen http://www.rug.nl/feb/education/complexity-uncertainty) as being normative, conformative, non-conformative, and anti-conformative that then drive emergent patterns of behaviour; i.e. an agent in those interactive categories can generate particular system patterns. Some can produce institutional 'lock-in', resilient to change, when only drastic changes in circumstances may cause this lock-in to be broken.

[14] See Kant's notion of "enlarged mentality" in Arendt (1982).

[15] Emery and Trist (1963) refer to this as a causal texture.

weakly held by formal structures (e.g. rules of law, ethics, the market place, etc.) and driven by their own OK-ness as the norm (e.g. making profit, survival of the fittest in the market place).

The assumption is that each relational context holds to a correspondingly different approach to choice-making (thence to decision risk (Douglas and Wildavsky (1982)) also the representations of choice embody the different natures of the agent's preference, belief and focus functions relating to being more or less attracted towards any of the four states. It is not so much that the four relational states are centres of attraction; it is more that the complex relational field or surface, which helps to differentiate between the four states, is acting to shape where an agent's socio-cultural relationships might be helping them to settle (i.e. at-traction) or making them feel a need to move away (i.e. negative e-motion). For example, put simply, a fatalist state of being has a more flattened preference function (i.e. there is no particular personal preference about potential consequences) and so choose-ables are more readily traded-in or traded-out (i.e. open to anything or not minding anyway). This can be compared with those corresponding to the other states, where there is more concern for one's own perspective and preferences and for appreciating and upholding those of others. As and when agents are drawn towards (or repulsed away from) any of the states, the ways in which they differentiate themselves from others or integrate themselves with others affects their choose-ables.

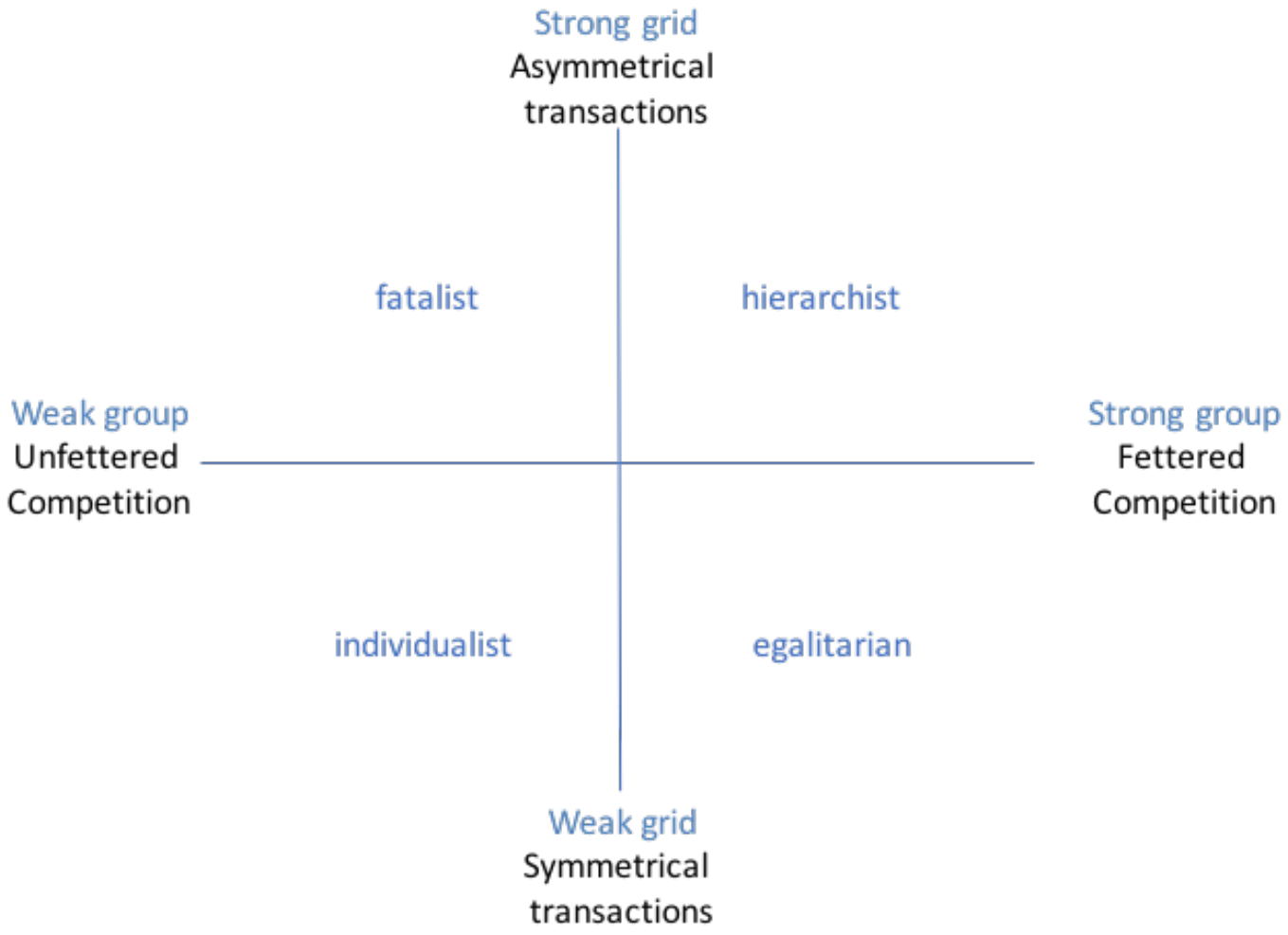

Figure 4: Relational states from Thompson's depiction of Douglas' grid-group frame (Thompson 2008)

If agents are openly, and coherently, well-integrated into their social context, then they are more likely to consider being open to other's choose-ables as well as their own[16]. If segregated, then they will focus on choose-ables that they know will maintain their own 'OK-ness'. The circumstances in which agents find themselves can have a strong bearing on the degree of autonomy and heteronomy that they are willing and able to accept (Smith and Dodd 2012). Thompson (1982) had added a power

[16] This would depend on whether or not they have a cohesive goal, as tight cohesion could result in adherence to goal-related task and 'group-think' confirmation. This is in contrast to being coherently aligned to a common purpose.

dimension to the grid-group model that would be necessary to consider in conditions where some agents assume positions of power in relation to other agents.

4. Adding descriptive mathematics: a step towards modelling

A more rigorous mathematical basis can be developed from the nature of variety in the different agents' *principles of being* that translate across into preferences for retaining choose-ables (and preferences for rejecting them). The mathematics expresses what might affect those preferences when circumstances present a need to resolve the principles of being, through trading-in or trading-out certain choose-ables, as and when there might be a contextual need for survival, coexistence, collaboration and cooperation. It also captures important differences in an agent's principles of being. For example, some agents may be unaware of (or indifferent to) other agent's preferences and care only for their own ways of being.

The mathematical essence is drawn from Catastrophe Theory (Zeeman 1977; Smith et al 1981; Smith 1983) that links four shaping coefficients[17] relating to different relational conditions and thence to different resultant choose-ables. The four shaping coefficients can be related to the following factors:

- Coefficient *a*: Combination of critical 'normal' factors used to monitor and maintain an agent's autopoietic sense of 'OK-ness'. This sense of 'OK-ness' can then focus choose-ables down to adaptive thresholds that are known to provide success, viability, homeostasis and/or survival.
- Coefficient *b*: Splitting 'confusion' factors that represent the degree of uncertainty, ambiguity or inconsistency being felt due to a situation being complex and/or pertaining to two or more conflicting perspectives. These factors can then be linked to the degree of certainty needed[18] by the agent concerning the on-going situation, state or status.
- Coefficient *c*: Belief 'bias' factors used for seeing biases and differences in projected futures (e.g. short-term vs long-term views) and beliefs in own and/or other agents' ideas of possible/likely/plausible futures. This links choose-ables either firmly to one agent's belief 'system' or leaves them open to a variety of other agents' beliefs about how things might go[19].
- Coefficient *d*: Assessment 'value' factors for evaluating and resolving preferences and perspectives when appreciating own and other agent's preferences and perspectives. An agent's approach to finding an appreciative resolution can lead that agent towards creation of new choose-ables (e.g. finding middle ground, resolution or compromises) that can to be readily accommodated into own preferences and into other's worldviews and ways forward.

The important thing to note is that these four coefficients not only change over time, as relational circumstances change, also they become more or less relevant when functional needs and living conditions change (i.e. need to be working in harmony with others and within a balanced position in the working environment[20]).

The Fold Catastrophe has only the first coefficient, so is appropriate for describing an agent's choice-making when there is just the focused objective of its own targeted priority. Here the choose-ables support only the focused utility of the immediate; for example, a financial trading agent according to factors contributing to coefficient *a* crossing a threshold value.

The Cusp catastrophe with coefficients *a* and *b* is the most familiar and is adequate to represent most agents' choice-making. For example, with sense of homeostatic thresholding being represented by coefficient *a*, and with degree of cognitive dissonance being represented by coefficient *b* the agent's choice-making could be represented descriptively. The cusp region represents an area of bi-stability where the choose-ables become increasingly binary (e.g. fight or flight) due to drift in their relational context, when tiny changes in conditions can result in a discontinuous shift.

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[17] There are a further three elliptoid catastrophes. This paper refers only to the cuspoids.
[18] This can, in extreme cases, lead to a bi-polar situation where the system flips between one choose-able and the other.
[19] See related ideas in Marsay (2014).
[20] Angyal (1958) termed these two conditions to be homonomy and heteronomy respectively.

A catastrophe equation with the first three coefficients is called a Swallowtail Catastrophe, where the choose-ables are mainly relevant for maintaining stability as the focus of interest, when any agent, relative to their changing context, is being put under strain. Any increasing systemic strain calls for all attention and importance to be placed on keeping everything stable[21].

The most rounded and socially open of the four catastrophe equations is the Butterfly Catastrophe, which has the stable choice outcomes (i.e. choose-ables) with all four coefficients coming into play. So the choose-ables are being scoped to take account of not only the agent's sense of own perspectives and preferences but also others' perspectives and preferences. The effect of nullifying the bias belief factor, (i.e. $c=0$), in the Butterfly Catastrophe is telling as it tends to build a pocket of stability[22], which relates to forming compromises for resolution to complex social problems (sometimes referred to as "clumsy solutions"[23]). If the bias belief factor is allowed to increase (i.e. $c>0$) then this puts pressure on one side or the other of the pocket of stability until it disappears, with the effect of increasingly biased beliefs for the agent, which tends to destroy any compromises (along with its holding context).

The introduction of coefficients *c* and *d* into agents' choice-making would appear to provide a more socially-based, human-like approach for agent-based models. Being able to describe and discuss such approaches for decision agent modelling would seem to be more appropriate for today's increasingly socially complex world. In addition, sharing of beliefs about plausible futures will help decision agents to avoid surprises and stalemating behaviour. Sharing of perspectives on what matters to other agents, and to society as a whole, helps agents to work towards choose-ables from a more holistic perspective of a shared purpose that can lead more readily to coherence in decision-making.

5. Conclusions

This paper re-introduces the term "choose-ables" because there does not seem to be a formal name for the concept of a choose-able; being the imagined deemed possible ways forward, that the agent has to construct, compose or create before they can begin to choose. The important point being that the nature of the deeming is subjective; according to that agent at that time and in terms of their particular circumstances. This paper addresses what, in terms of human, organic, social, organisational, institutional constructs, might affect, adjust, adapt or shape an agent's choose-ables.

Two foundation theories are presented, Catastrophe Theory and Culture Theory, that combine to provide a way to describe human, social, institutional, organisational changes as a kind of dynamic landscape, over which an agent might be working and adapting to sustain themselves, to maintain appropriate levels of comfort, stability and balance, and to be in harmony with others. The constructs draw together the mathematical basis for discontinuity and non-linearity, as proposed by Catastrophe Theory, with recent developments in Culture Theory. Indeed, clumsy solutions from Culture Theory and the Butterfly Catastrophe are descriptions of the same phenomenon. These are also linked to the subjectivity of choose-ables, as proposed and developed by Shackle in his imaginative and original studies on economic choice.

Two practical triangular constructs are offered to aid access to an agent's implicit rationale for choice. The triangular constructs help to discuss degrees of freedom for choice and to understand possible rationales for an agent's state of closed-ness or openness to ideas and of having enough capability 'bandwidth' in terms of the scope and nature of their choose-ables. Their changing conditions, when

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[21] For example, the likelihood of an over-loaded ship capsizing can be described by a swallowtail equation. Geoffrey Vickers in his book "Freedom in a Rocking Boat: changing values in an unstable society" (1972) captures the essence of the difficulty here in trying to open-up the range of choose-ables, when the focus is on stabilizing and normalizing.

[22] Christopher Zeeman puts it beautifully (with author's notes in Zeeman (1977): "In applications concerning the emergence of compromise, the butterfly factor [d] will increase with time [if held and supported by agent in context]; at first the compromise is fragile, in the sense that its stability is broken by any perturbation across the nearby sides of the pocket; but as the pocket grows in size the compromise becomes stronger, in the sense of being stable under increasingly large perturbations."

[23] Thompson (2008) refers to these as "clumsy solutions".

working within an institutional or organisational structure, or cultural set of norms, would naturally affect the choose-able bandwidth.

The ideas put forward in this paper offer a useful support to Drama Theory and a practical addition to Decision Theory and Game Theory, as they provide ways to take into account the broader context, as changing conditions tend to make an agent adapt and adjust their choose-ables. The constructs help to relate the difficult subjective concepts of subordination, rules, norms, taboos, beliefs, myths, biases, preferences, focus of attention, and provide insights into the ways in which these might affect and shape an agent's choose-ables. The influence of any cultural relationships on an agent's adherence to, or blindness within, such a cultural context may then also be more readily understood and more openly appreciated. The simple constructs can help to work through questions to uncover assumptions about an agent's rationale and what may have brought them to a dilemma or to carry out a specific action. For example, why might an agent be assumed to have only that set of options? Can we imagine ourselves in their shoes (and in their heads) so that we can begin to ask questions and support an appreciative inquiry? The simple constructs offer a place to start to open up the dialogue, upon which other methods and techniques can then build.

So, theories of choice-making need not be limited to the analysis of option selection, set within an objective, psychological context. This paper provides ways of opening out the study of an agent's choice-making by imagining and conceptualising their rationales for trading-in or trading-out their choose-ables according to their social, personal, organizational, institutional and cultural contexts, and their openness (or otherwise) to adapt to their changing circumstances.

In summary, the constructs suggested here offer initial ways to support an appreciative inquiry about an agent's relational context and may help to understand why their choose-ables may be limited. This limited degree of freedom for choice can in turn limit an agent's scope of view and openness of mind to others' viewpoints and perspectives. The drawing together of catastrophe theory and culture theory offers new ways of seeing and imagining the shaping effects of relational contexts on an agent's choose-ables, that then act as a medium through which agents are drawn to make choices and carry out observable actions. The non-linear mathematics does not and cannot offer objective solutions to problems. As in Shackle, the unknown variable "x" is subjective and the equations capture openness to others' preferences, beliefs and perspectives.

The strength of the combination of the two theories lies in their descriptive power of subjective, relational concepts that hitherto have tended to remain hidden and tacit. Being able to describe and discuss these concepts in decision agent modelling would seem to be helpful and appropriate for today's increasingly socially complex world. In addition, sharing of beliefs about plausible futures will help decision agents to avoid surprises and stalemating behaviour. Sharing of perspectives on what matters to other agents, and to society as a whole, should help agents to work towards choose-ables from a more holistic perspective of a shared purpose that could lead more readily to coherence in decision-making.

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Contribution Statements from Co-authors

Publication 1

My recollection was that a key part of the drafting process for the paper took place during a one day session with you, Prof Jim Smith and me present. Both you and Jim took the lead in this session and in subsequently producing the final paper for publication

I am thus very happy to confirm your key role in developing the substance of the paper.

Best Regards, Professor James Moffat, Quantum Gravity Group, Dept of Physics, University of Aberdeen

Publication 1

I enclose a statement about two papers that we coauthored and my contribution to these.

- Dodd L, Moffat J, Smith JQ, and Mathieson G (2004) Discontinuity in decision-making when objectives conflict: a military command decision case study, International Symposium on Military Operational Research, UK. http://ismor.cds.cranfield.ac.uk/21st-symposium-2004
- Dodd L, Moffat J, Mathieson G and Smith JQ (2003) From simple prescriptive to complex descriptive models: an example from a recent command decision-making experiment. *Proc. 8th International Command & Control Research & Technology Symposium*, National Defense University, Washington.

This paper concerned an analysis of military experiments. My contribution to this work was minimal. I helped embed the ideas of the other authors - mainly those of Lorraine - within a formal Bayesian Decision theoretic framework. But Loraine was very much first author on this using her domain understanding and skills as a mathematician into crafting these ideas together.

Jim Q. Smith, Professor of Statistics, University of Warwick

Publication 2

I enclose a statement about two papers that we coauthored and my contribution to these.

- Dodd L and Smith J Q (2013) Devolving command decisions in complex operations, Journal of the Operational Research Society, 64:1, DOI: 10.1057/jors.2012.7

This paper was again predominantly Lorraine's conception and she did most of the writing. I helped to analyse some of the implications of her ideas within a mathematical framework through my familiarity with Catastrophe Theory. But the underlying taxonomies and their interpretations both logical and psychologically within combat decision making and protocols were all hers (as well as a good proportion of the mathematics).

Jim Q. Smith, Professor of Statistics, University of Warwick

Publication 4

DODD L AND MARKHAM G (2013) - ORDERS OF C2 AGILITY AND IMPLICATIONS FOR INFORMATION AND DECISION-MAKING

In the broadest terms, this paper follows the historical pattern of Dodd / Markham collaborations in that the substantive material and domain knowledge was provided by LD and the attempts to systematize this into some kind of framework (e.g. structure of Table 1 and its explanations, structure of Table 2) were initiated by GM. The final paper was the result of extensive co-drafting and co-review.

The paper builds on the consolidated views of 'forms of time' in an earlier joint paper, where again the principal GM contribution was the graphic reproduced as Figure 1.

Most of the text therefore originates with LD's expression of domain knowledge (e.g. all discussions of decision-making, choices and value, comfort and discomfort). This is also reflected in the references, at least half of which were identified solely by LD.

Some specific areas in the paper merit further clarification of the relative contributions:

- The commentary following Table 1 and through to Figure 5 was constructed jointly during the writing of the paper.

- The brief section entitled 'the exercise of agility through interaction between orders' was a GM extrapolation.

- Figure 7 and the text immediately surrounding it was another GM extrapolation, albeit an unwise and speculative effort which has subsequently mystified even its originator – it is only now, with LD's most recent work on the hierarchy of orders, that this rather odd figure has been re-habilitated and the significance of the idea behind it has re-emerged.

- All mentions of 'information' and 'message-passing' would have been drawing on GM's own previous work.

Overall, LD's contribution to this paper is substantially reflected in the core domain material in this paper, with GM's efforts being largely confined to using this material to populate structures such as that offered by Table 1, and thence focussing on the significance of those structures themselves.

Geoff Markham

Publication 5

Re: Dodd L and Alston A J (2009) Complex Adaptive and 'Inquiring' Systems Theory for Contemporary Military Operations: A Multi-perspective Approach, The Cornwallis Group XIV: Analysis of Societal Conflict and Counter-insurgency, Vienna

Lorraine,

To confirm your contribution to the above paper.

Dodd L and Alston A J (2009) Complex Adaptive and 'Inquiring' Systems Theory for Contemporary Military Operations, is based upon a paper that Lorraine and I wrote for the 25th ISMOR symposium in 2008 (and was awarded best paper). Lorraine and I worked jointly on the Multi-perspective approach (MPA) that we presented in that paper. In the 2009 paper Lorraine has extended the MPA and has built an Afghanistan/IED example to show its use.

The 2009 paper represents a significant improvement to MPA and provides evidence of its potential utility that was not in the 2008 paper.

Regards

Anthony

Anthony Alston

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