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VARIETY DYNAMICS: A NEW BODY OF SYSTEMS METHODS AND A NEW MATHEMATICAL FIELD FOR MANAGEMENT AND CONTROL OF DYNAMICALLY COMPLEX MULTI-ACTOR SYSTEMS

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Abstract
This paper provides an overview of Variety Dynamics theories, systems methods and mathematics to control complex and hyper-complex systems extending Systems Science beyond its causality-based limitations. 'Complex' refers to systems whose behaviour is shaped by multiple feedback loops. 'Hyper-complex' refers to systems whose structure does not conform with conventional systems' assumptions. Real world examples have continuously changing system architecture and changing control arrangements multiple subsystems that vary in ownership and purpose, and variable system boundaries. They include disasters, wars, epidemics, climate management, financial management, diplomacy, terrorism, health systems and national economies. Causality-based systems approaches do not easily address hypercomplex systems. Variety Dynamics was developed to address this issue. It integrates morphological analysis of Zwicky, decomposition methods of combinatorics design, and early use of variety in systems by Ashby. Over 45 Variety Dynamics axioms have been developed. These are intrinsically self-evident and describe how the distribution and dynamics of distribution of variety in a situation interrelates with and influences, the trajectories of coercive control and its ownership in complex and hyper complex systems situations. Examples and a brief overview of mathematical foundations are provided.

Keywords
Complex systems, Variety Dynamics, coercive systems, hyper-complex systems, non-linear multi-actor control theory

1 | Introduction

This paper provides an overview of the development of Variety Dynamics as a suite of theories and systems methods to analyze, manage and control complex and hyper complex systems.

Variety Dynamics was developed to address the weakness of contemporary causally based System Sciences methods in addressing many complex real-world situations.

Currently, Variety Dynamics comprises: an approach to managing complex systems consisting over 45 axioms guiding systems management decision-making; new definitions of 'complex system' and 'hyper-complex system'; a new approach to management decision-making relating to complex systems; formal explanation of the limitations of existing causally based systems science approaches, and an abstract mathematical representation of Variety Dynamics theories, axioms and principles.

In short, Variety Dynamics provides an alternative foundation for some key aspects of the international systems sciences field that enables management of manty real world systems currently outside the remit of systems science. The sequence of the paper is as follows:

- Identification of problematic features of common real -world systems situations that place them outside the scope of conventional Systems Science approaches.
- Surfacing the central role of prediction in all activity and the System Science's dependence on prediction via causality.
- Variety Dynamics and its key concepts
- Explanation of a Variety Dynamics axioms
- The mathematical foundation of Variety Dynamics is outlined.
- Two examples of the use of Variety Dynamics axioms in real-world hyper-complex situations are provided as an indicator of scope.

2 | Characteristics of Real Systems problematic for Systems Sciences.

Current Systems Science and Operational Research theories and methods depend on the situation to be managed having the following characteristics:

- That the system structure remains constant for the period of analysis and prediction
- That the sundry ownerships, purposes, roles, motivations, relationships of different elements of the system and its controlling subsystems remain constant.
- That the system and subsystems and systems elements remain within the system boundaries
- That the effects of the environment on the system and subsystem structure, ownerships, purposes, roles, motivations, and relationships are predictable.
- That knowledge of the causal relationships is sufficient for mechanistic prediction of behaviours and there are not missing realms of information that make modelling, analysis and prediction of behaviours and outcomes impossible.

Systems Science and Operational Research theories and methods have difficulty addressing and managing the many typical real world, complex multi-actor dynamically changing systems situations that have one or more of the following characteristics:

- Systems with multiple changing system and subsystem ownerships
- Systems in which systems and subsystem purposes, perspectives and motivations change dynamically and unpredictably.
- Systems with a variety of changing power and control subsystems and subsystem relationships.
- Systems in which dynamic subsystem and system arrangements reflexively influence the system environment (and hence reflexively dynamically change the structure, relationships, ownerships and purposes of system and subsystems)
- Systems in which system structure, subsystems and their purposes and boundaries are changing dynamically.
- Systems that have aspects of the system and its subsystems functioning at times outside the system boundary.
- Systems with multiple dynamically changing feedback loop relationships between subsystems, environment, system and control actors
- Systems in which the external environment is changing and influencing a wide variety of factors, actors, purposes, system resources, system and subsystem behaviours and abilities within the system.
- Systems in which a substantial proportion of subsystems and system characteristics are unknown and dynamically changing in ways that, with other dynamic factors, influence system behaviours and system structure.
- Prediction, system behaviours and outcomes may be independent of observable causality.

Systems with the above characteristics we refer to as hyper-*complex systems*. Such *hypercomplex systems* are epistemologically different to but may include complex *systems* whose behaviour is defined by multiple feedback loops (Love, 2009, 2018a, 2021). Many common real-world situations are *hyper-complex systems* with one or more of the above characteristics and examples include epidemics, energy infrastructure, environmental issues, economic competition, IT development, politics, war, etc.

Conventional Systems Science approaches are ill-suited to understanding and managing *hyper-complex system* situations because *hyper-complex systems* do not satisfy the assumptions of Systems Science methods and theories. As a result, Systems Science approaches are unable to justifiably predict the system behaviours and outcomes resulting from management and control interventions. Hence, for such systems, Systems Science methods and theories do not provide a valid basis for management and control, because decision making without the ability to predict outcomes from those interventions is guesswork rather than management.

To date Systems Science and Operational Research practitioners have overlooked the above issues and instead attempted to compensate for the lack of competent ability of Systems Science and Operations Research to address hyper-complex situations by a variety of compromised approaches that typically result in flawed outcomes, e.g.:

- Simplifying the practitioner's model of complex and hyper systems so they are merely complicated systems for which the Systems Science assumptions can then be mistakenly assumed to apply.
- Applying mathematical mechanical modelling of causes and effects despite its limitations for
- Attempting to guess or ignore actual system functioning by using social methods s, or the graphic methods such as those of Bob Horn (Horn, 2001).

- Attempting to guess the outcomes resulting from management decisions by using participatory or collaborative methods.

Because the above approaches act to ignore that the situations in focus operate outside the assumptions of Systems Science, the above simplifying practices exist as delusional or wishful thinking by systems academics and practitioners who apply them in those contexts. None are effective at predicting behaviours and outcomes in relation to hyper-complex systems and cannot provide the basis for understanding system behaviours or for identifying justifiable management interventions.

3 | The Central Role of Prediction in Systems Science

The above section focused on the assumptions of Systems Science. This section introduces the role of ***prediction***. In terms of usefulness, it can be seen to be deontically self-evident that:

> *The primary and essential function of ANY theory, analytical method, decision-making or design guide is predicting the behaviours and outcomes that will result from any changes.*

At root, this central and essential role of prediction in all theories and methods goes back to the epistemic role of prediction in providing the utility of ANY metaphoric system: and theories, methods, practices, thoughts, feelings, intuitions, categories, systems and all real or abstract and mathematical entities and relationships are all metaphorical systems (see, for example, Indurkhya, 1992, 1997; Lakoff & Johnson, 1980; Lakoff & Núñez, 2000; Manin, 2008).

When we make a model, or theory or any other representation of the world, we do so because it gives us the ability to make better decisions to change the future. For any such model or representation to have any usefulness it must in some way give us predictive information about the consequences of our actions and decisions.

Biologically, prediction as the means of creating reality of the moment is now increasingly accepted as the primary biological process of the brain as described in 'predictive brain theories (see, for example, Bubic, Yves von Cramon, & Schubotz, 2010; Luzak, McNaughton, & Kubo, 2022; Nave, Deane, Miller, & Clark, 2020; Venter, 2021; Yon, Heyes, & Press, 2020). These findings of predictive brain research debunk the traditional idea that thinking consists of first sensing and then processing what is sensed. Instead, the recent evidence has required a shift of understanding to the idea that the primary purpose of the brain is prediction and that what we see, hear and think and our sense of 'reality' are in fact predictions of the brain based on its current best evidence and modified continuously moment by moment considering new evidence. Moving from the neurology of the brain to practical agency, it is self-evident that the primary reason for when we have any kind of thought or emotion, is to predict the future consequences of our actions and decisions to provide us with competitive advantage.

Prediction is central and essential even in purely descriptive theories and methods. For example, if we say, 'this is a cup' we are predicting that, usefully, for the next short while at least, the object will remain, and have the properties of, a cup. Similarly, when we classify a particular political or financial decision-making as socialist or conservative, the essential usefulness of this classification is its prediction of associated behaviours, decisions and consequences. Another example, when we refer to a day as 'sunny', the primary reason for the usefulness of the description is in predicting what is possible on such a day as opposed to a day that is 'rainy and windy'.

To recap, bringing it back to the focus of the paper, all conceivable systems, situations and processes for their functioning depend on **prediction**, and as such, **prediction** is the central and essential role of all theories and methods of Systems Science. The value of such theories, methods and practices of Systems Science depends on the validity, accuracy, and effectiveness of their ability to predict the behaviour of systems and outcomes due to that behaviour. For systems management or any kind of management, if prediction is absent, management interventions are simply unprofessional guesswork.

The above immediately elevates into view a variety of questions essential to understanding the limits of validity of systems theories, methods, and practices in terms of prediction:

- What are the limits to individual humans' abilities to predict the behaviour of systems and subsequent outcomes?
- What are the limits of specific systems theories and methods in terms of prediction of system behaviours of systems and subsequent outcomes?
- What are the limits of specific systems theories and methods in predicting system behaviours of systems and subsequent outcomes due to step changes and surprises in system factors?

4 | Limits of Causality as the basis for Prediction in Systems Science

Management of systems depends on ***prediction*** both in the practices of system management and in systems theories and methods that underpin them. Focusing on the processes by which prediction is undertaken in Systems Science is also the epistemologically obvious, but rarely implemented, starting point for all critical analysis of systems theories and practices.

Prediction can have many different foundations such as prior experience, theory models, analogy, AI, biology etc. To date, however, observation shows that Systems Sciences theories, methods and practices have focused almost exclusively on *prediction of outputs* based on **causality**. This observation and its limitations apply across science, as outlined in detail by Cambridge quantum physicist Matletto (2022, ref).

How causality underpins prediction in System Science (and the central role of prediction) can be seen perhaps most simply in terms of managing a simple three element linear system as shown in Figure 1. One aim of management is to **predict** the behaviour of C **caused by** changes to A and or B. An alternative and often more common practical alternative is the inverse; **predicting** what changes in A and B will **cause** the preferred behaviours of C.

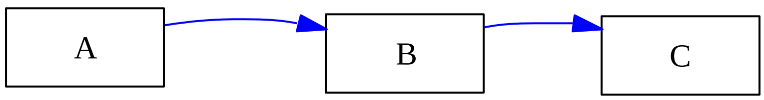

Figure 1: Predictive causal relations in simple system

The above dependence on causality and prediction of behavioural and state changes between elements is the essential conceptual basis of Systems Science theories and the basis of systems software such as Vensim, Dynamo or Anylogic.

Considering the foregoing, several reasonable and revealing questions to ask are,

- What are the limits of using causality as the basis for the prediction?
- What alternatives are there to causality as the basis for prediction?
- What are the limits of the alternatives to causality as the basis for prediction?
- Is there a higher level of analysis that can encompass theorising about alternatives to causality as the basis for prediction?
- How can the above be represented and prediction undertaken mathematically on the different bases for prediction?
- Are there alternatives to prediction for successfully understanding and managing complex and hyper-complex systems?

Earlier this paper outlined systems characteristics of *hyper-complex systems* for which conventional causality based predictive System Science methods do not apply.

A key overarching challenge for the validity of Systems Science is that these characteristics are typical of the kind of systems that are the primary interest of Systems Science and its primary claim to value.

The characteristics of hypercomplex systems apply to disasters, managing complex manufacturing processes, war, politics, social services, diplomacy, health problems such as obesity. managing large organisations, disease management, epidemics, hospital systems, climate change, drug control, international relations, financial systems and their breakdown, transport systems, urban planning, managing crime, domestic violence, gender and diversity issues,

To recap, the characteristics of such hyper-complex systems include:

- Situations in which the system structure changes dynamically during management.
- Systems in which the sundry ownerships, purposes, roles, motivations, relationships of different elements of the system and its controlling subsystems vary and are changed by elements outside the system in focus.
- Where system and subsystems and systems elements exist at least in part beyond system boundaries and their behaviour is changed by elements outside the system in focus.
- The effects of the environment on the system and subsystem structure, ownerships, purposes, roles, motivations, and relationships are NOT predictable.
- Knowledge of the causal relationships is NOT sufficient for mechanistic prediction of behaviours and there are missing realms of information that make modelling, analysis and prediction of behaviours and outcomes impossible.
- It is not possible to guess the outcomes resulting from management decisions by using participatory, collaborative, or other social methods (e.g., systems exceeding the 2-feedback loop law).
- Step changes in the system and its environment
- Information about causality and key causal pathways is incomplete, missing or not modellable.

In short, prediction of system behaviour and outcomes necessary for effective management and control of the systems most of interest in Systems Science is typically not possible using the conventional Systems Science approaches that depend on causality for the prediction necessary to make management decisions. As explained elsewhere (e.g., Love, 2009, 2010, 2018a) that where situation behaviours or outcomes result from the actions of multiple feedback loops, participatory, and other collaborative systems methods are similarly intrinsically invalid for these kinds of systems. Instead, what is required is an approach that offers a higher level of analysis that addresses the questions raised earlier in this session.

The authors developed the field of Variety Dynamics, to address the above questions and to provide an alternative approach to effectively managing such complex and hyper-complex systems on a different basis to the causally based predictive methods of Systems Science.

In Variety Dynamics, complex and hypercomplex systems are managed by controlling the trajectories of the ownership and control of subsystems and the relevant aspects of the external environment. Unlike conventional Systems Science and similar approaches to prediction Variety Dynamics analysis is independent of and different to causally based analysis does not depend on knowing the details of causal relations or actions.

5 | Variety Dynamics: Trajectories of Ownership and Control as an Alternative to Causality for Control of Highly complex Systems

Behaviours of hyper-complex situations such as epidemics, disasters, policing, economic management and war are dominated by dynamics of ownership and purposes of controlling elements along with possible options for decisions. Causality and prediction of outcomes are secondary.

Example: The cold war following World War 2 was enacted through proxy wars, influence on governments of allies and others and activities that sought to reposition each side in terms of its current power and potential for future acquisition of power and control in the world. Misinformation and disinformation were key components of such a cold war. Each side was required to make decisions about deploying forces, influences, resources and incitements; where to deploy them; and through which organisations. Conventionally, warmaking decisions depend on predictions of outcomes caused by different decisions on the basis of military theories, moral forces and political decisions such as Clausewitz (1984) The system boundary is the war zone. In the cold war, however, the situation is much more complex and strongly shaped by actions of a wide variety of actors, many of whom have substantial controlling influence at a distance by a wide variety of different means. Actors include the US government, industrial lobby groups, Russia, Iran, China India, Australia. Europe, South American countries, their power proxies, and all their international and local economic and political policies and agreements, along with citizen groups in a variety of countries. As the dynamics of the situation change, power and control structures change as do ownerships and purposes of elements with power and control. Agent/country allegiances change along with active war faring/terrorist agent groups who may have a wide variety of different roles: as an army, as terrorists, as government, social services provider, diplomatic force, economic entity, agent of others…. For such a hyper-complex situation, decision-making via predictions based on simple causality is ineffective and almost irrelevant. Decision making for such hypercomplex situations must be at a higher level.

Variety Dynamics is a higher-level approach to managing and controlling hyper complex situations. It guides decision making to modify the structure of the situation to appropriately influence the trajectories and availability of power and control rather than trying to influence the situation directly.

6 | Variety Dynamics: Key concepts

Variety Dynamics is primarily concerned with the management and control of hyper-complex systems for which it is not possible to make a causal model, especially because the systems' structures, ownerships and motivations are dynamically changing and at times not-necessarily contained within the system structure.

Such hyper-complex systemic situations are common in the real world in politics, warfare, business competition, terrorism, diplomacy, policymaking, policing, financial systems, transport, manufacturing, managing epidemics, and global health, disruptive and accretive innovation, and all those real world systemic situations that are traditional simplified because they are problematic to address them Systems Science, Systems Thinking and Operational Research.

There were two theoretical foundations of Variety Dynamics. Structurally, Variety Dynamics was developed from ideas grounded in the Morphological Analysis of Fritz Zwicky (Zwicky, 1969; Zwicky & Wilson, 1967) and later similar design decomposition ideas expressed by Alexander (C Alexander, 1963, 1964; Christopher Alexander, 1979; C Alexander & al., 1977; C Alexander, Ishikawa, & Silverstein, 1968, 1977) together with the Law Requisite Variety developed by Ross Ashby (Ashby, 1956; Conant & Ashby, 1970). Over time it became clear, however, that these ideas are somewhat predated in Middle Eastern writings of a millennia ago. Morphological analysis in its current form almost certainly originated in Zwicky's 1945 report in German war research based on interrogation of German scientists that remains restricted access (Zwicky, 1945). However, the concepts clearly appear in 'Morphological Astronomy' (Zwicky, 1957) and with the fully developed version of Morphological Analysis available in Zwicky (1969). Morphological analysis and decomposition provide the theoretical foundation of options-based approach to modelling and analysis in Variety Dynamics.

It was during the same period, Ashby identified Ashby's Law of Requisite Variety, which for Variety Dynamics provided an axiomatic basis for theorising the role of variety in power and control of systems (see, for example, Ashby, 1956; Conant & Ashby, 1970). Ashby's Law is stated in many different ways. Perhaps the most straightforward is,

The variety available to the controller of a system has to be greater than the variety capable of being presented to the controller by that which is intended to be controlled.

In the above, *variety* is the number of options available as choices for different parts of a system. For example, if there are five different kinds of cups in a cupboard, then someone choosing a cup is facing a variety of 5.

Alternatively, consider the relative power relations in someone looking for films form an online film service. Imagine the individual is looking to choose 3 different films for a weekend from an online service with a variety of 100,00 different films. In this case, the person will be easy to satisfy, and the power is with the person making the choice. However, imagine where variety of supply is limited to only two films on a shelf, then the situation changes. The person making the choices has now lost much of their power to be able to choose. However, the person could look to a different supplier, thus changing the dynamics of distribution of variety and achieving more power and control. This starts to indicate the role of the distribution of variety in the relative ownership of power and control.

Variety Dynamics takes Ashby's definition and inverts and extends it as Variety Dynamics Axiom 1 to apply more generally without losing any of the self-evident axiomatic nature of Ashby's Law,

The relative ability of a system element to influence system behaviours depends upon the dynamic relative balance between the variety available to it, and the variety presented by other elements of the system.'

Starting from this, simple but more broadly-based Variety Dynamics Axiom 1 restating Ashby's Law of Requisite Variety law, becomes obvious that in a hyper-complex situation, the distribution of variety becomes of determining significance in terms of power and control, as does the dynamics of distribution of variety. The latter is because the ability to change the distribution of variety in a situation enables an actor to rearrange the variety to increase their own power and control relative to other actors.

The application of Variety Dynamics Axiom 1 is demonstrated in the following example.

Environmental activists requested the Federal government to implement a higher vehicle emission standard. The vehicle manufacturing industry used its wealth and influential lobbying power to block the standard. The environmental activists then persuaded different states to set different standards (they increased the variety to which the manufacturers were exposed). The vehicle manufacturers were now faced with the costs and difficulties of increasing their variety (manufacturing different vehicles for different states, restrictions on movement of vehicles etc.) and capitulated and agreed to the implementation more stringent national emissions standard.

The above example, provides is a specific example of a general Variety Dynamics principle comparing the relative value of variety and force:

In complex situations, the ability for an actor to manage variety can result in them having more control than the use of absolute power, resources and force.

In short,

Management of variety offers more power and control of outcomes than does resources and force.

The military history of the world is replete with examples of this Variety Dynamics principle: from Chengis Khan's Mongol invasions to Vietnam, Iraq, Afghanistan and submarines. Typically, in asymmetric warfare, one side uses its ability to increase variety beyond that which the other side can respond and thus over time achieve transfer of power, regardless of opponents' resources and power. An example is the success of Chengis Khan's small Mongol army with limited armaments and resources Chengis' army took on and conquered a complex, well-established highly governed and fortified world with many self-supporting powerful and wealthy interests, populations, and fortified city states allied together across China and Asia. Chengis Khan's army, however, had variety on their side. They lived with their ponies off the land wherever they were. They travelled quickly, could change plans quickly, and could assemble and reassemble in different configurations at different places. They could at any location quickly build the war machines necessary (e.g. siege engines) and thus not be restricted by transporting them. They could make allies and enemies at will to change the flow of power. In contrast, his opponents in city states had relatively fixed arrangements with almost no variety possible in their behaviour and decision making. The advantages offered Chengis Khan's army by their ability to bring large amounts of variety of actions against their enemies was more effective than the lower variety of responses of their enemies in spite of their considerably greater wealth, resources, fortifications and armaments. The variety wielded by Chengis Khan's armies allowed them to direct action against the weaknesses in their opponents. Over time, Chengis Khan's ability to provide a higher variety of warmaking strategies led to the governance of a large portion of the world being transferred to Chengis Khan and his army and administrators. Additionally, the ability of the Mongols to use variety was also brought to peacetime governance and this variety increased the pace of development of the world they conquered and improved the lot of its peoples and, later, their elites. This is a straightforward example of the management of variety offering more control than wealth, power and resources.

At a trans-national level, the applicability of Variety Dynamics can be seen in the use of geopolitical and other forms of foreign influence and interference to gain political advantage by shifting the distribution and dynamics of variety via changing the decision and decision-making options available to different actors.

In technological situations. Variety Dynamics approaches include modifying the distribution and dynamics of variety to change technological and legal control trajectories, e.g. to influence the processes creating standards, or restricting access to technology and innovation knowledge, such that it changes the balance of commercial advantage. Sanctions are an example.

In all cases, Variety Dynamics includes using changes in variety to influence or manipulate the locus of ownership and control of systems and subsystems; including the ability to create new subsystems and move them partially or wholly inside and outside of the system boundaries.

In Variety Dynamics, the use of *variety* to exert power and control provides a completely different basis for managing highly complex systems compared to conventional causality-based Systems Science approaches.

7 | Variety Dynamics: Examples of Axioms

Axioms are *self-evident* statements of characteristics and relationships.

The axioms of Variety Dynamics are straightforwardly self-evident in that they are all consequent on Ashby's Law and cannot be interpreted via causality explanations. From experience, the easy-to-understand self-evident nature of Variety Dynamics axioms requires only the observation that control depends on variety, and putting aside attempts to understand them via habits of seeing the world only through the mechanical causal explanations typical of Systems Science. A similar observation is made by quantum physicist Marletto in her book 'The Science of Can and Can't' (Marletto, 2021). As a parallel to Variety Dynamics and similar to Zwicky's morphology, Marletto makes the claim that mapping the counterfactuals of a situation, which are exact equivalent to variety, enables better understanding and prediction of outcomes, and that attempting to use causality and the 'mechanical' modelling typical of science is intrinsically problematic. Causally based Systems Science approaches are similarly subject to Marletto's critique, being part of science in general.

The distribution of variety and the dynamics of that distribution relate directly to system and environment architectural factors that include systems structure (e.g., hierarchical), timing and time trajectories (especially time differences between information and action), influences on ownership and motivations (e.g. bull or bear market, herd instincts, nationalism); differences in the trajectory of variety (e.g. design and innovation infrastructure, individual maturity and flexibility) etc.

Key factors in Variety Dynamics are:

- Structure of the power and control situation in focus and its dynamics (systems, subsystems, boundaries etc.)
- Distribution of variety
- Dynamics of distribution variety (including generation)
- Role of time
- Dynamics of ownerships of system, subsystem and environment elements
- Relationships between elements

Variety Dynamics was initially developed as axiomatic extensions of Ashby's Law of Requisite Variety demonstrated self-evidently via examples.

At the start of development of Variety Dynamics, its axioms were originally seen as extensions of Ashby's Law. In the parallel mathematical development of the foundations of Variety Dynamics, the axioms were seen as being similar to the mathematical axioms of Geometry: as descriptions of relationships between primitives. In Geometry, the primitives are points, lines, circles etc. In Variety Dynamics the primitives are varieties, distributions, power and control. In this sense, the axioms of Variety Dynamics are seen as the axiomatic basis of a mathematical topic concerned with the application of a multi-dimensional 'variety space' that influences the flow of power and control in a situation.

The axioms of Variety Dynamics describe particular ways that variety modifies the locus and ownership of control in particular circumstances. For example, Axiom 2 extends Axiom 1 to describe the specific form of relationship between variety and changes in power and control trajectories particular to hierarchical systems.

Variety Dynamics axioms have two main purposes. The first is to describe the structurally different ways that changes in variety influences trajectories of power and control in morphologically different situations. The second is as guidance in achieving a transition of control by those individuals and organisations managing complex situations such as: system managers, military commanders, union officials, negotiators, parents, teachers, drug and alcohol addiction specialists, public health professionals and all interested in managing and controlling complex and hyper-complex systems. Variety dynamics provides guidance in their decisions about interventions intended to result over time in transfer of control to those using the axioms.

Following initial work in the late 1990s and early 2000s leading to the first six Variety Dynamics axioms (see, for example, Love, 2002, 2018b; Love & Cooper, 2007a, 2007b, 2007c, 2008, 2021), the authors have now developed forty-five Variety Dynamics axioms. These forty-five Variety Dynamics axioms, together with the parallel development of Variety Dynamics as a mathematical field, together form the axiomatic foundation for Variety Dynamics as new, separate, coherent body of Systems Science theory, methods and mathematical topic independent of, and different to, traditional causality-based Systems Science approaches.

General principles of Variety Dynamics include:

1. The variety available to a situation comprises the sum of the optional states available to each variable in that situation.
2. The locus of power and control in a situation depends directly on the distribution and dynamics distribution of variety relating to that situation.
3. The dynamic distribution of variety in any situation or system can be represented mathematically.
4. The outputs of system and subsystems, and the consequent outcomes of complex and hyper-complex systems depend on the distribution and dynamics distribution of control varieties and system varieties.
5. Variety distribution is always dynamic and shapes the ownership, control and outputs of systems, subsystems, and related environments.
6. Changes in the physical and temporal distribution of variety can be used to control and manipulate system and subsystem outputs.
7. Specific interventions to change the locus of power and control and outputs and outcomes can be identified for particular complex and hyper-complex system archetypes.
8. The variety of a situation maps directly onto the combined problem and solution space of that situation in design terms.
9. The two-feedback loop law means that interventions to change the locus of power in hyper-complex systems will be intrinsically covert.
10. Variety Dynamics does not require identifying causal relations in a system/situation.

Here are five examples drawn from the forty-five Variety Dynamics axioms identified by the authors that are self-evidently grounded in Axiom 1.

Axiom 2: Hierarchical systems*: For complex, layered and hierarchical systems involving multiple constituencies in which the distribution of variety generation and control is uneven across the system THEN the differing distributions of generated and controlling variety result in a structural basis for differing amounts of power and hegemonic control over the structure, evolution and distribution of benefits and costs of the system by particular constituencies.*

Axiom 2 follows self-evidently from axiom 1 and applies to situations structured hierarchically in a layered manner such as armies and universities. Axiom 1 applies to all systems regardless of their structure and describes how in general control depends on the distribution of variety. Axiom 2 self evidently applies the same reasoning to structured situations, specifically those structured hierarchically. It self-evidently states that the hierarchical structure of the situation results naturally in a hierarchical structural basis for how distributions of variety shape power and hegemonic control and the distribution of benefits across the different constituencies involved. Practically, this means that using variety to change the trajectories of power requires working within and across the hierarchies of power – or acting to minimise the effects or existence of those hierarchies of control.

Axiom 10: Using feedback loops: *In complex systems in which multiple variable sources of variety generation and variety control interact and in which control varieties are generated dynamically to respond to changes in system varieties THEN relative control of the feedback loops driving control varieties shapes the future distribution of power and hegemonic control between sub-systems and constituencies over the structure, evolution and distribution of benefits and costs of the system.*

This axiom focuses on using control of feedback loops generating variety to change the trajectory of control of power. Examples include control of the agenda or minutes of committees involved in creating laws and standards. Again, axiom 10 follows self-evidently from both axiom 1 and axiom 2. Feedback loops offer systems of leverage in which variety can be increased (positive feedback loops) or attenuated (negative feedback loops). Axiom 10 states self-evidently that control of such abilities to influence variety in a situation provides the ability to modify the trajectories of power, resulting in changing the future distribution of power across constituencies, changing the structure of the situation, and changing the future distribution of benefits and costs.

Axiom 16: Service system design: *Service design involves variety distributions in at least two systems of which both generate and control variety:*

- *Entity providing the service.*
- *Entity receiving the service.*

For a service to be successful, the variety dynamics of both entities must be functional. That is the control systems in each entity must have a greater variety than the variety of that entity's system.

Axiom 16 is self-evidently based directly on axiom 1 and applies it to both the system providing a service (e.g. online app) and the system receiving the service (e.g. user and their technology). For those designing service systems, this axiom self-evidently identifies that for a service to be successful, the control systems of both service provider and service user must be adequate: they must a=have greater variety than the systems being controlled. Examples of failures include the design of online apps, and government systems that are too complicated for users or require different technology (e.g. the user has a landline, and the service has been designed to be only available through the internet).

Axiom 28: Transaction costs limits: *The ability of a controlling or coercive agency to increase its variety (in scale, in distribution or its dynamics) to increase its potential for power and control is limited by the increase in transaction costs associated with generating, using and managing the additional variety. The benefits of additional variety are in the limit offset or overcome by the associated Coasian transaction costs.*

Axiom 28 emerges self-evidently from combination of Axioms 1 and axiom 16 with Coase's theories of transaction cost. Benefits of economies of scale result from initial increases in organisational size, but this is not unlimited. Axiom 28 describes how self-evidently increases in size of organisation result in combinatorial increase in variety of the number and types of relationships internally and externally with additional increases the concomitant variety of systems to manage the increased variety of relationships and associated actions. Coasian transaction costs are associated with all these combinatorial increases in variety. In other words, there is eventually a diseconomy of scale due to the costs associated with variety that offsets and eventually overcomes the benefits of increase in scale.

Current examples include banking systems and consultancy services which initially expanded due to reduced transaction costs converting from paper-based systems to online. Now the problem of combinatorial increase in variety appears in limits to size. Military systems have a similar trajectory in which small autonomous units demonstrate lower cost and better functional effectiveness than military actions involving large scale integration of centrally commanded forces.

Axiom 34: ***Covert nature of control in multi-feedback loops:*** *Humans cannot mentally predict causal outcomes of situations whose behaviour is shaped by two or more feedback loops (two feedback loop law). Where Variety Dynamics interventions are implemented in such situations, the actions and consequences are intrinsically causally covert and opaque to the mental perception of those involved who are not consciously managing the locus, distribution and dynamics of variety.*

Axiom 34 builds self-evidently on Axiom 1 and the direct implications of the two feedback loop law (Love & Cooper, 2007b). It affirms that interventions based on Varity Dynamics axioms will continue to change the locus or trajectories of power and control and related ownerships, whilst at the same time, these consequent changes in control are unable to be mentally predicted via causal ways of thinking. That is, the subsequent changes in system - behaviour, outputs and outcomes of situations with multiple feedback loops subjected to interventions based on Variety Dynamics cannot be mentally predicted or understood by individuals or groups of individuals operating according to causal ways of thinking. This means they are effectively covert to analysis by causal Systems Science or

Systems Thinking methods. In essence, this means that, in almost all cases, the actions of Variety Dynamics interventions are hidden from those using conventional causal systemic analysis. That is, in those situations, it will not be possible for observers or participants to predict system behaviour and consequences except through a Variety Dynamics analysis or similar methods that are independent of causality.

8 | Variety Dynamics: Practical Examples

Below are three short real-world examples of situations for which Variety Dynamics analyses offer explanation. In some cases, these demonstrate the ability for Variety Dynamics to correctly predict outcomes in contradiction to the conventional causal analyses that led to incorrect predictions.:

- Murdoch publishing empire defamation case against Crikey online newspaper
- US invasion of Afghanistan
- Proprietary control of the Semantic Web of digital education

1.1 | Crikey vs Murdoch.

Lachlan Murdoch, co-owner of the Murdoch media empire took to court the small independent news outlet Crikey for accusing him of being an unindicted co-conspirator of the riots in support of Trump at the US capital. The imbalance in power, wealth, resources, and influence between the international Murdoch media empire and the tiny Crikey online newspaper is immense. A simple casual analysis predicts Murdoch will obviously win.

Crikey responded to Murdoch's legal threats by increasing its controlling variety by first publishing Murdoch's threatening letters via an advertisement in the New York Times and the Canberra Times, then by defending via 'fair commentary on matters of public interest' and thus legally opening discovery to be able to make public a wide range of Murdoch business related documents. In contrast, the variety of the Murdoch position was limited and restricted to arguing the Crikey claim was false and further limited by the legally restricted range of potential variety that could be used in court (compared to attacking Crikey in the media).

Crikey was able to influence the distribution of variety in such a way that it exceeded the variety Murdoch could control. The result was that Murdoch withdrew the legal action. In short, the comparatively high variety that Crikey could bring to bear in the variety-limited environment of the court meant that power flowed to Crikey than was available to Murdoch, that in spite of the overall immense power imbalance between the two organisations. The Variety Dynamics analysis is obvious and correct, in contradiction to the causal analysis. Moreover, the Variety Dynamics analysis required considerably less access to detailed information than would a formal Systems Science causal analysis to predict the outcomes.

A Variety Dynamics analysis of the situation at the outset indicates that flow of power and control towards Crikey and away from Murdoch can be achieved via two variety strategies. The first is to escalate publicly and increase the public aspects of variety associated with Crikey. Crikey's journalists are in a more flexible position in public discourse and media than those of Murdoch because of the latter's economic need to align their responses with the politics of their supporters and customers. The second Variety Dynamics strategy was to direct the conflict into a legally controlled situation in which many forms of media-based variety otherwise available to Murdoch are attenuated and at the same time, the use of the truth test results in the court using its control variety (via discovery) to legally expose a large amount Murdoch owned economically valuable information. Some of these latter may have the potential to turn the case in Crikey's failure directly. Other aspects of it might result in economic, social or political embarrassment leading to economic loss or loss of influence. Thus, Variety Dynamics can at the outset predict successful strategies resulting in flow of power and control to what appeared to be the weaker party. As an aside, the same kind of Variety Dynamics approach is available to organisers of workers subject to pressures from powerful organisations.

1.2 | US invasion of Afghanistan

The US invaded Afghanistan following the actions of Al Qaeda. A causal loop model (Figure 2) mapping counter insurgency causal relationships to support counter insurgency decision-making and predicting outcomes of different strategic decisions.

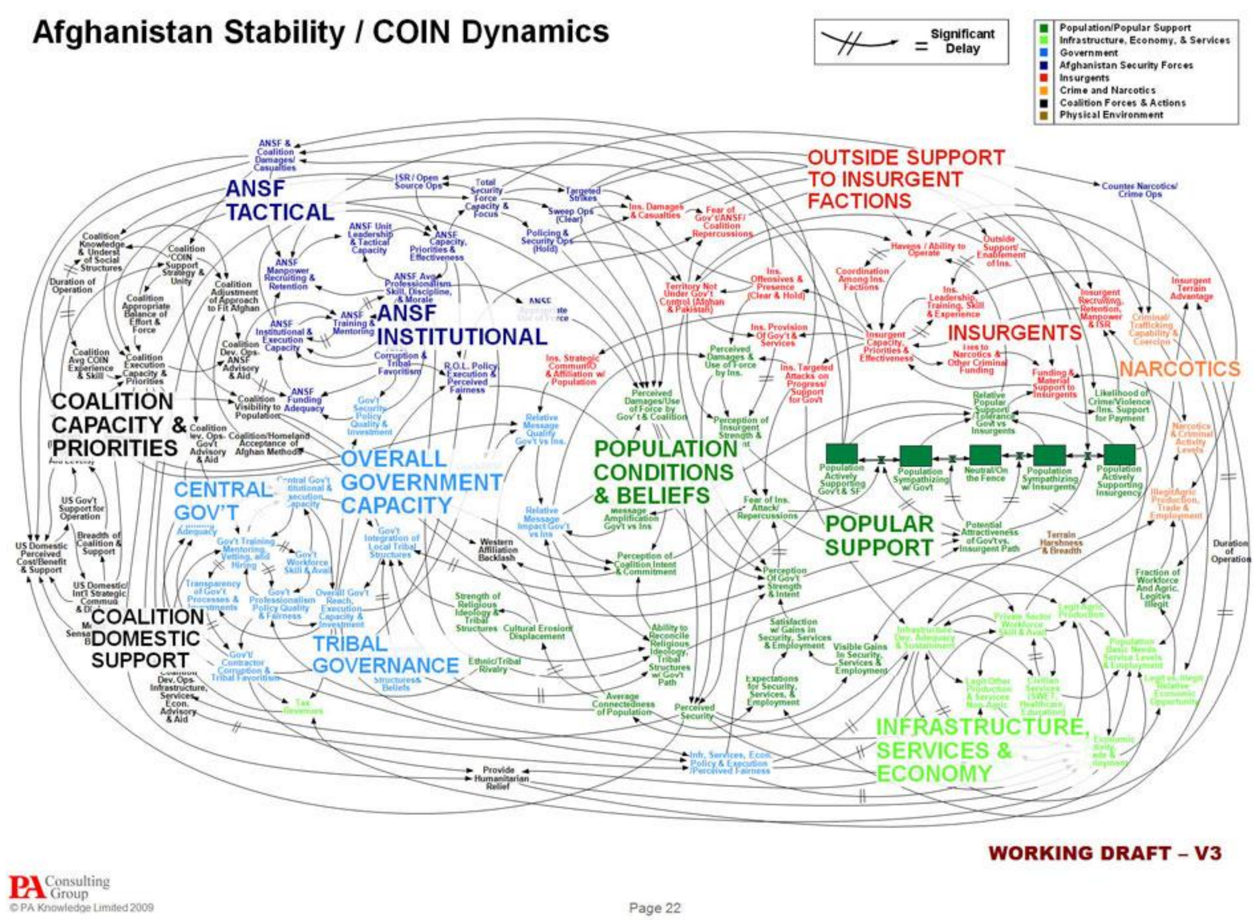

Figure 2: Afghanistan COIN Dynamics Causal Loop Model

This diagram was created by the US military to assist their Counter Insurgency activities in Afghanistan. When presenting it in Kabul, US military General Stanley McChrystal stated, "When we understand that slide, we'll have won the war".

As soon as this diagram had been created. Variety Dynamics could immediately offer two insights derived directly from it with negligible additional information. The first is from Axiom 34. The behaviour of the situation mapped in Figure 2 results from more than 2 feedback loops. Hence, the situation cannot be mentally understood, or the behaviour and outcomes mentally predicted either an individual or any group. The implication being that the US military will never be able to win the war in Afghanistan based on understanding and predicting outcomes from this figure.

The second insight from Variety Dynamics, is from visual inspection of the diagram in terms of the distribution of variety and the potential for dynamic increase in variety. The areas with the most opportunity for any side to increase in variety at the expense of the other side are located on an axis from top right to lower left. That is the areas relating to insurgents and their support across to tribal governance. The potential for these areas to increase the variety of things the US has to respond to results in combinatorically escalating costs for the US to provide and manage an ever-increasing variety of control responses. In Variety Dynamics terms, axioms 1, 2, 10, 28 and 34 described above all apply. They indicate the trajectory of control will flow over time towards the insurgents and tribal governance and away from the US invasion forces and the US installed government and much of this will be hidden to US causal analysis, and, regardless of the difference in power, resources and wealth, eventually the economic constraints will result in collapse of US control due to diseconomies of scale.

Variety Dynamics indicates that the US would have had a better opportunity for change the locus of control in Afghanistan towards itself by strategies that offered ways to increase the variety that insurgents were exposed. Diplomatic relations and supportive complex economic, technological, educational and law providing arrangements would offer such an opportunity that would likely result in some participation in control and governance.

9 | Variety Dynamics: Mathematics

In parallel to its axioms and practical role in guiding managers of complex systems to undertake successful interventions, Variety Dynamics is emerging as a mathematical topic based on and extending the mathematics of morphological analysis.

Mathematically, as described earlier, Variety Dynamics offers an alternative representation of complex systems to the conventional causally based approach to prediction. Viewed abstractly, Variety Dynamics provides a n alternative approach to modelling systems as an n-dimensional dynamic mapping of options (variety) for each factor in each element of a system and its subsystems, along with the functional mapping of the mechanisms that relate these options and their selection.

In contrast to casually based mechanistic modelling, the focus of Variety Dynamics is primarily to model and manage over time the dynamic trajectories of the subtle transitions of ownership and control of agency directing, influencing and controlling the decisions that eventually result in outputs and outcomes. This new and different mathematical and conceptual approach to understanding, representing, managing, and controlling complex and hyper-complex systems is done via a focus on the dynamics and distribution of variety in such systems and their environments.

The central element, or unit of analysis, of Variety Dynamics is **variety**, considered as a measure of the **options** available within a set and, at least in the simplest cases, is equinumerous to Cardinality. The central focus of Variety Dynamics is the way varieties change over time due to multiple factors including the selection, amount and changes in varieties of other classes, sets, sub-sets and environmental factors within the situation in focus.

Variety Dynamics as a mathematical topic is founded on a combination of Set Theory, Differential Topology, Graph Theory, Model Theory and Field Theory (specifically following Zermelo-Frankel set theory). These are used to define a body of theory around the concept of a 'variety dynamic distribution' as a field (the 'v' field) in which variety entities can also include the topology, locality and differentiability of the variety field entities. Mathematical assumptions of behind the modelling of Variety Dynamics in mathematical terms include:

- Sets are viewed as dynamic, changing over time due to influences from elsewhere. That is any set that is in focus has a boundary and set contents defined functionally from elsewhere.
- Variety, as the number of feasible options of a variable, acts mathematically as a cardinal number with several additional operational features that enable it to be functionally defined.
- Variety cardinality and its distribution and behaviour in a system is variable over time.
- Variety cardinality in any set, class, system, or subsystem, is changeable and functionally related over time by members of other sets set, class, system, or subsystem.
- Power and control are important dimensions of dynamic set behaviours.
- The distribution and dynamics over time of power and control is shaped by the distribution and dynamics of variety (cardinality) and its relationships.
- Considered in variety terms; the varieties and their distribution and dynamics and associated systems, subsystems and their behaviours and environments are represented in Hilbert spaces, regardless of whether they are viewed analytically or topologically.

The above set theory approach outlining the main features of the topic of variety was originally grounded in Zermelo–Fraenkel set theory with the axiom of choice (ZFC), and then later Von Neumann–Bernays–Gödel set theory which enabled the inclusion of classes, and from there to Morse–Kelley set theory enabling the use of bound variables over classes (Bagaria, 2021; Hallett, 2016) and for a history of development of set theory see Ferreirós (2020). For practical reasons, currently Variety Dynamics is being explored as pocket set theory of third order arithmetic described by Holmes (2021) or, alternatively using type theory as an alternative to the earlier set theory foundations in which variety is linked to its type...

In terms of the earlier sections, this is extending the meaning and use of *variety* in Variety Dynamics beyond the *variety* of cybernetics states of a finite-state machine and extends the role and purpose of *variety* as a fundamental driver and component of the ownership of power and control of highly complex systems.

10 | Conclusion

To summarise, this paper has introduced Variety Dynamics theories and a suite of Variety Dynamics methods to address complex and hyper-complex systems that are beyond what can be validly addressed by the current methods of Systems Science. The paper identified characteristics of classes of complex and hypercomplex systems that cannot be addressed by conventional Systems Science approaches. It outlined the reasons for considering prediction is central to systems management and demonstrated the limits of causality for using Systems Science for real world systems. The paper introduces the conceptual and self-evident axiomatic basis of Variety Dynamics as an alternative approach to managing real world hyper-complex systems for which conventional causally based Systems Sciences approaches are inappropriate. Brief practical examples of Variety Dynamics are provided along with an outline of its mathematical representation.

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