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Applying complex adaptive system thinking to Australian health care: Expert commentary

Report for an Australian Commonwealth Government agency

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Acronyms and abbreviations

ACGA	Australian Commonwealth government agency
AHRQ	Agency for Healthcare Research and Quality
CAS	Complex Adaptive Systems
CDC	Centers for Disease Control and Prevention
DSS	Decision support systems
GP	General practitioner
IHI-QI	Institute for Health Improvement Quality Improvement
LHD	Local Health District
NHS	National Health Service
NIH	National Institutes of Health
PHN	Primary Healthcare Network
PPCHC	Person- and people-centred healthcare
RCA	Root cause analysis
WHO	World Health Organization

Executive Summary

This expert commentary has been commissioned by the Australian Commonwealth government agency (ACGA) and the Sax Institute to contribute to a series of consultation and discussion papers on its future vision for the Australian Healthcare system.

The Report is structured to respond to specific questions posed by the Commission in the commissioning brief. In the report, each question is addressed from the perspective of two broad approaches found in the literature; 1) 'systems thinking approaches' in applied analyses of healthcare, and 2) 'complex adaptive systems theory' as a global theory to understand health care.

This report has been specifically commissioned as an expert commentary rather than a systematic review of the literature. We therefore began with published literature known to the authors of this review. This was supplemented a Medline keyword search, grey literature and iterative discussions and commentary with successive drafts a) within the core (author) group and b) in consultation with an external expert panel.

Conceptual overview

Contemporary health policy faces several wicked problems. Individual, isolated changes have foundered in the face of this complexity. A broader systems' perspective is required to understand how changes intersect, affect one another or create new conflicts and synergies.

Complex systems are composed of many interacting components (agents) that are characterised by different levels of variability, uncertainty and levels of organisation. Complex adaptive systems are a particular type of complex organisation characterised by feedback – learning and self-adaptation leading to emergence of new properties. That is, the agents of a complex adaptive system are able to learn from experience and adapt to changes in the environment, and new agents and connections emerge.

Along a continuum, different types of systems can be classified as simple, complicated, complex (dynamic) and complex adaptive systems.

- In **simple systems**, elements of the system interact in one-to-one relationships producing predicable outcomes.
- **Complicated systems** have sophisticated configurations but highly predictable behaviours (e.g. a car or a plane). Interactions between the elements in the systems are also linear and predictable.
- **Complex systems have two key characteristics, they self-organise without external control and exhibit feedback resulting in newly created, i.e. emergent (at times unforeseen), behaviours.**
- **Complex systems also tend to be open, loosely bounded, and influenced by its environment. Complex systems are simultaneously a subsystem of a larger system and comprised of a number of subsystems.**
- **Complex adaptive systems (CAS) are a special case of complex (dynamic) systems as they have elements (agents) that can learn and adapt their behaviours to changing environments.**

We use the term **systems thinking approaches** to refer to a broad set of perspectives, methods and approaches developed in diverse areas of science, organisational management and engineering which are increasingly being applied in health policy and planning.

Health interventions are one of the priority areas for systems thinking analysis. Systems thinking can inform health policy and program assessment and planning in that it elucidates how an intervention:

- couples and embeds within context and manifests itself in thinking and practice;
- changes relationships;
- displaces existing activities (which may account in part for intervention effect); and
- redistributes and transforms resources (material, informational, social, cultural).

Complex adaptive systems theory seeks to make sense of how complex systems, such as social systems and health systems operate and function. It seeks to define how, and why, an order exists within these systems, despite the (complex) nature of relationships and the emergent (and therefore not precisely predictable) nature of outcomes.

A healthcare system is a social system; described in the complex adaptive systems theory literature as emerging based on common statements of purpose, goals and values.

- Values: refers to the ideals and customs of a system toward which the people/agents have an effective regard.
- Having agreed purpose, goals and values defines the **driver** of the system; together they give rise to so called "simple rules" that coherently direct the interactions within a CAS.
- "Simple rules" provide the necessary "safe space/freedom" to adapt agents' behaviour under changing conditions.
- Complex adaptive systems cannot be controlled, the direction of their development can be guided and requires **leadership** that reinforces the organisation's purpose, goals and values.

There is little doubt that health systems are complex, however, there is widespread disagreement as to whether they act as complex adaptive systems in accordance with complex adaptive systems theory. This is because health systems appear to struggle in response to changing demands (such as a change in the morbidity patterns) and the defining purpose, goals, values, and central drivers remain elusive.

Question 1: How does the concept of a complex adaptive system apply to the Australian healthcare system?

Systems thinking approaches

Our knowledge of the characteristics and dynamics of overall health care systems is still in its early stages. However, there are plentiful examples of tools, methods and applied analysis from various disciplines that can be utilised for describing and understanding the components of health care systems. **System engineering** focuses on how to design, operate and measure complex systems over their life cycles, and how to analyse and improve its efficiency, productivity, quality, safety. **Business analytics** has developed techniques that incorporate modelling, knowledge management, expert knowledge, artificial intelligence and visualisation. **High risk industries** and sectors such as commercial aviation and extraction use systems thinking to conceptualise adverse events. Decision support systems (DSS) and toolkits are used in **defence, business, policy, education and healthcare**. DSS, including simulation models and agent-based modelling, play an essential role in the development of knowledge-to-action strategies. Finally, **geographical information systems** can be used to represent the distribution of agents, their connections and spatial relationships.

Few examples of the analytical techniques above use the full complex adaptive systems framework, however, each of the approaches summarized above – and many more – are making valuable use of systems thinking to develop analytical and policy tools to understand health systems.

Complex adaptive systems theory

Based on the principles that define organisational **complex adaptive systems in CAS theory** the Australian health system has to be considered to be a CAS. It has:

- agents – (eg. health ministers, health financing organisations, hospitals, the various health professionals, and individuals) and
- these agents interact and through these interactions, learn – e.g. in consultation, within a hospital, between central bureaucracies and local health service units.

However, as the purpose, goals, values and simple rules of the Australian health system are not clearly evident, the system as a whole has no identifiable unifying driver. The lack of a unifying driver makes the

Australian health system look more like a "conglomeration of discrete units", colloquially expressed as "**a fragmented health system**". Therefore, according to complex adaptive systems theory:

- Understanding the health system as an integrated CAS requires reaching agreement of an overarching driver.
- Most adapted solutions for the problem of a subsystem will emerge from helping all agents of that system to align their drivers with those of the whole system.

Question 2: In considering the Australian healthcare system as a CAS, what agents exist at a macro, meso, micro and nano level and what are the relationships between them?

Systems thinking approaches

- Systems approaches to health care assessment and planning usually define agents, but do not use the macro-meso-micro-nano schematic. In part, this is a response to the blurred lines of connectivity and location of action in a complex system.
- Schemes using these levels can be complemented by the Donabedian quality of healthcare model – which uses the categories of 'structure', 'process' and 'outcomes' – and extended by adding geographic levels (country, local area, individual).
- (Social) network analysis and systems modelling techniques (multi-scale, dynamic, multi-level) are increasingly being used to analyse connections between agents in a complex system.

Complex adaptive systems theory

This layered conceptualisation of the health system is consistent with the complexity notion of nested systems found in CAS theory. There are obvious constraints on agents at any system level in taking a 'whole of systems' perspective. This is because:

- Values, goals and drivers of different sub-systems may not be the same – or may even conflict
- It is difficult to determine the potential influence that action in one part of the system may have on other parts of the system.

Strong goal-driven links between and across organisational levels would increase the robustness and adaptability of the system.

Question 3: In considering the Australian healthcare system as a complex adaptive system, where do consumers fit and what are their relationships with other agents within the system?

Systems thinking approaches

- Users (or consumers) are present in the system in many different roles. In such situations they are frequently negotiating competing interests.
- Users' response to interactions with other agents and events within the system depends on the combined weight of those interactions, but also broader influences such as their personal social or financial situation, social, political or religious settings and particularly their prior experience of care.
- There is widespread agreement that users should be engaged in health care decision making. Key approaches include 'citizen juries', co-design and co-production, collaborative care, self-support and peer support.

Complex adaptive systems theory

- Complex adaptive system theory recognises individual-level agents as having similar properties: they are autonomous, they interact with other agents in the system along multiple pathways, they learn and they adapt their behaviour.

- Full engagement of users is essential to achieve a user/patient-centred health system.
- Taking a whole of system perspective, users always play a key role in determining the purpose and goals of a system.
- Users can play such a key role during phases of re-build, re-design or during slower pace change.

Question 4: How can an understanding of the Australian healthcare system as a complex adaptive system accommodate or support adoption of person-centred care?

Systems thinking approaches

- The enabling and delivery of PPCHC, with its focus on customising care to the needs of individuals, inevitably adds even greater complexity to the system.
- There is a great potential for widespread adoption of mapping and modelling techniques in the Australian health system to aid health planning and policy to move the system closer to delivering PPCHC.
- However, there is a need for caution. Even the most comprehensive models require some level of aggregation of preferences, actions and consequences. Decisions based on models can be a step closer to PPCHC, but are still not adapted entirely to the individual. Rather, models assist decision-makers to become aware of how a system works and apply this knowledge in practice.

Complex adaptive systems theory

- To move the Australian health system towards a complex adaptive system that is coherent and goal-delivering, a focal point (driver) is required to guide activities to achieve integration within and across organisational levels of care.
- Taking a CAS theory approach, the main challenge from the whole of system perspective relates to how to transform and solidify the values that sustain the system.
- System change requires leadership in finding the right driver for the health system. This could take the form of a system-wide conversation about general expectations and approaches to healthcare

Introduction and methods

This expert commentary has been commissioned by the Australian Commonwealth government agency (ACGA) and the Sax Institute to contribute to a series of consultation and discussion papers on its future vision for the Australian Healthcare system.

The commissioning brief outlines the vision of ACGA to support the creation of a person-centred healthcare system. In the portfolio of activities in moving towards this vision, the Commission proposes to adopt a systems approach. It is envisaged that this perspective will offer a practical insight into the interplay of roles, responsibilities and opportunities that exist within the system – providing a foundation for navigating the enablers and constraints to person-centred care.

The commentary team has been engaged to offer independent expertise and experience to prepare this plain English account of complex adaptive systems thinking. This paper has thus been prepared with the following as its guiding purpose:

- To offer a clear, concise overview of the language and concepts found in Complex Adaptive Systems (CAS) literature
- To demonstrate how these concepts perform when related to the Australian healthcare system – in relation to 4 key questions posed in the commissioning brief.
- To demonstrate the practical benefits of complex adaptive systems thinking in a range of scenarios when moving towards change.

During the preparation of this expert review two positions were found in the literature.

The first looks at the general problem of complexity, and the (often eclectic) theoretical and practical approaches that start from the recognition that systems thinking is the starting point for understanding contemporary health care. These essentially applied approaches to the use of 'systems thinking' and 'complexity' use various techniques to map relationships, identify feedback loops, find gaps in knowledge or explain particular successes and failures within a system. The focus is on how core elements *within* a complex system interact and thus the implications for policy drawn from this body of literature focus on solving problems and progressively moving towards more people and person centred care

The second approach draws on 'complexity science', a more holistic theoretical approach with its origins in various disciplines such as physics, biology and environmental science. We outline the key elements of complex adaptive system theory and use metaphors to demonstrate how complexity science can be applied as a global theory to understand how health care, as a complex (adaptive) system, can be defined and how it functions. This approach focuses on the structure, drivers, and the overarching direction of a system *as a whole*. Policy implications drawn from this body of literature support a complete shift in health prioritisation, planning and decision making in order to steer the system in the direction of people and person centred care.

Each section of the report is dedicated to a specific question posed in the commission brief. Under each question, a subheading "systems thinking approaches" and "complex adaptive systems theory" is used to reflect this division within the literature. It is important to note that this distinction is one of degree – proponents of complex adaptive systems theory would accept most if not all the analytical methods found in complexity approaches. However, they would situate these in a more thoroughgoing complexity science.

All the experts in the working group agreed on the need to move towards a systems-based approach in health care policy and planning, as systems thinking can help us understand problems arising from either the structure and/or interaction of agents. This approach has the capability to identify potential solutions to complex problems that may otherwise remain hidden.

The commentary team agrees with the definition of health care systems as complex systems as described by the *Institute of Medicine* and reiterates that a deeper understanding of health care systems and their behaviour is required:

> *Health care is complex because of the great number of interconnections within and among small care systems . . . Health care systems are adaptive because unlike mechanical systems they are composed of individuals - patients and clinicians who have the capacity to learn and change as a result of experience. Their actions in delivering health care are not always predictable, and tend to change both their local and larger environment (1)*

Specifically, in relation to the goals of the ACGA to navigate enablers and barriers to system change:

- Systems thinking refers to an emergent field of understanding that focuses on the relationships between the parts of a system.
- Health care systems are complex systems and analysing their structure and function is useful for policy planning.
- Systems thinking can help us understand problems and identify potential solutions to these problems that are not obvious – because they lie in the dynamics of the system, rather than in specific parts of the system.
- Adopting complex systems approaches can bring to light how events, or change, in one part of the system affect other parts of the system.

Literature capture

This paper has been specifically commissioned as an expert commentary rather than a systematic review of the literature. For this topic, we consider this appropriate. Systems science in healthcare is still emerging and we draw upon sources from highly diverse fields which would be unlikely to be captured in any meaningful way in a strict systematic search. We therefore began with published literature known to the authors of this review. This was supplemented by:

- *Medline* search using the keywords "(complex adaptive system)*" and "(healthcare system)*", period to end of 2015
- Grey literature from reputable national and international agencies (e.g. WHO, King's Fund, NIH)
- Iterative discussions and commentary with successive drafts
    - Core group
    - Consultation with external Expert Panel
- Review and revision of paper in light of expert input.

These papers were then drawn on to inform the commentary, distinguished from a traditional systematic review in that:

1) database searches served to complement review team knowledge of seminal papers;
2) papers found were not subject to a systematic quality appraisal process - rather;
3) expert knowledge was sought to appraise the evidence in light of the questions posed by the commissioning agency.

Structure of the paper

Each section of the paper responds to a specific question posed in the commissioning brief and sets out approaches to the problem identified with complexity theory. It then applies the perspectives of complex adaptive systems theory to the problem. It is important to note that the two approaches are not necessarily incompatible. CAS theory (or science- a terminology adopted by expert commentators who adopted this

approach) uses many of the methods developed by analysts of complexity, but in in the context of an encompassing theory, claiming application in domains of physical, biological as well as social spheres.

Conceptual overview

Why take a systems perspective to health care?

"Waste in the health care system" refers to unnecessary health expenditure and unexplained clinical practice variation, system inefficiencies, and costs and consequences of medical errors and other problems in health quality and safety (2). Australia shows good health indicators at the macro level, but waste in the health care system is a serious concern for the sustainability of our health care system. (3, 4) The increasing waste in health care has been compounded by the increasing complexity in the patients treated in the system, the interventions provided to these patients and the organisations providing care. Health care policy and planning has struggled to keep up. Paradoxically, cutting edge technical and scientific improvements coexist with outdated logistics and lack of integration. "We bank, shop, book taxis and airplanes... on our smartphones. But for most people, when it comes to seeing a doctor or getting a blood test, we dial the clock back 20 years" (5).

Individual, isolated changes have foundered in the face of this complexity. A broader systems' perspective is required to understand how changes intersect, affect one another or create new conflicts and synergies.

Systems thinking approaches

Systems thinking is an area in health research that analyses the parts of a defined system and their connections in relation to the whole. Related approaches and terms found in the literature include 'systems approaches', 'systems science', 'complexity analysis' and 'design thinking'. In this paper we use the term *systems thinking approaches* to mean the broader set of perspectives, methods and approaches developed in diverse areas of science, organisational management and engineering which are increasingly being applied in health policy and planning (6).

Complex systems are characterised by different levels of variability, uncertainty and levels of organisation that range from simple systems to highly complex ones. A complex organisation cannot be replicated and the capacity to predict its evolution and to generalise its outcomes is limited due to the properties of complex dynamic systems, mainly non-linearity, time-dependency and context-dependency. Complex adaptive systems are a particular type of complex organisation characterised by feedback – learning and self-adaptation leading to emergence of new properties. That is, the agents of a complex adaptive system are able to learn from experience and adapt to changes in the environment, and new agents and connections emerge. Systems thinking approaches recognise these characteristics and shape research questions, methods and analysis accordingly.

The systems thinking approach has long been applied in areas such as business, engineering, defence, and public policy. Health care is a late adopter of this approach but the interest in health systems research and planning is surging. Related areas such as global health, collaborative care, or health systems engineering are attracting growing attention, and systems thinking is particularly relevant in health sectors characterised by high complexity, such as chronic care, primary care and mental health care. Systems thinking is key to designing and assessing integrated care and this approach has been adopted by WHO for the new strategy

"People-centred Integrated Care for All". It has also been adopted by several health planning agencies such as NHS Scotland and the Department of Health in the Basque country (Spain).

What are the building-blocks of information needed for systems thinking?

According to systems thinking approach, health systems should be described in terms of their boundaries, drivers, agents, and connections.

- **Boundaries and context.** Systems thinking requires information on the hierarchy and the context of the system that is analysed, particularly in relation to the boundaries of the system, the subsystems which can be identified within the system, and the different levels of organisation where agents operate. As complex dynamic systems are context-dependent and time-dependent, context analysis is a necessary component of any analysis. Similarly, the understanding of the history of the development and evolution of a system is also relevant to understand its current status.
- **Agents.** Agents in a health care system include patients, citizens, health professionals, research and clinical units, hospitals, service providers, governments (government departments), advocacy organisations, insurers, health related businesses, bureaucrats, peer groups and individual users.
- **Connections.** Connections describe the relationships between every agent in the system as the different organisational levels at which they operate and that together characterise the level of complexity of the system. An interaction is the occurrence of an action in the connection between two agents that produces an effect. Health interventions are a particular type of interaction between patients and professionals, or between the population and public health agencies.
- **Drivers.** Complex adaptive systems theory claims that identifying the 'core driver' of a system is critical to understand the system and to guide change. However, there is a lack of critical information on the drivers of the health care system, even at local or sub-system levels. Applying systems thinking to healthcare systems is enabled where there are clear drivers, however analysis may need to proceed knowing that drivers may vary, or even conflict, across parts of the system.

In order to apply systems thinking to the design and monitoring of health care it is important to gather information on every one of the major components of the system: Boundaries, Drivers, Agents, and Connections. (See Figure 1) (7);

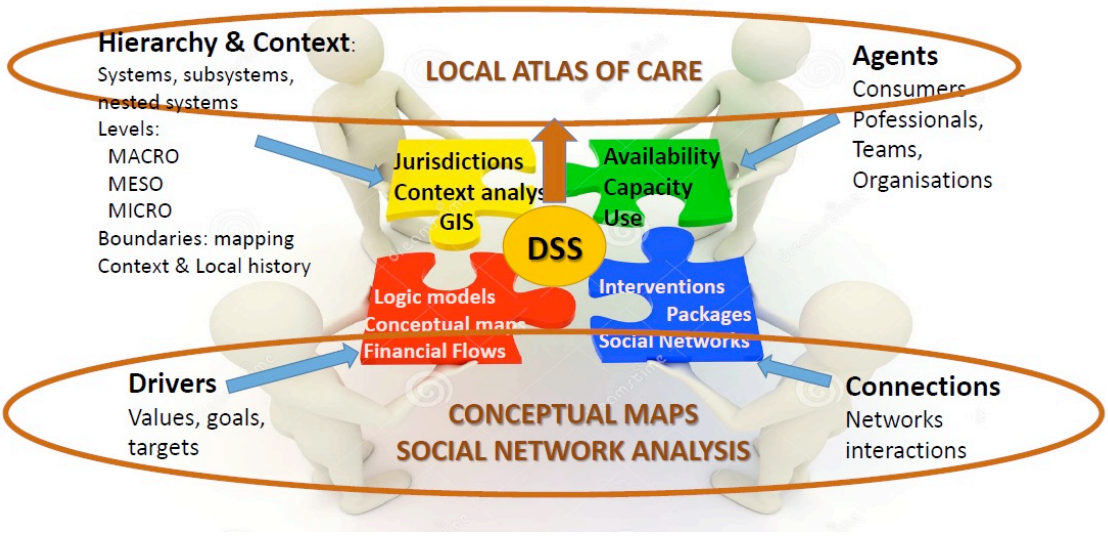


Figure 1: Main components of a complex health care system and items relevant for their analysis and development of decision support systems (DSS)

Application of systems thinking to analysis

Determining the effects and effectiveness of health interventions is one of the priority areas for systems thinking, with significant implications for health policy and program evaluation, systematic review of evidence, analysis of quality, safety and efficiency and for implementation. "Interventions are more effective and sustainable when these complex and multilevel aspects are understood and considered" (8).

From a systems thinking approach health interventions can be defined as a particular type of formal interaction between agents (most commonly users, health professionals, organisations and institutions); or as occurring events in the system (9). Programs and interventions can also be conceived as evolving networks of person-time-place interaction. This observation invites research on how an intervention:

a. couples and embeds within context and manifests itself in thinking and practice;
b. changes relationships—patterns of information giving and seeking, support, practical help, role taking, skill use, decision-making, collaborating, competing, etc.;
c. displaces existing activities (which may account in part for intervention effect); and
d. redistributes and transforms resources (material, informational, social, cultural).

The capacity for an intervention to redistribute resources is its chief mechanism to address inequity, whether the resources are taxes or new educational opportunities and skills. (10)

Systems thinking deliberately moves away from the most commonly used methods to determine the cause and effects of interventions, or events, on specified outcomes. Established methods – such a linear regression modelling – rely on assumptions about the variables in the causal relationship, such as their independence and unidirectional cause-effect relationships. Systems approaches as outlined above, adopt various methods to capture the complex nature of multi-directional, overlapping relationships, feedback loops, learning and compounding effects of multiple changes within the system.

Key messages for policy

- **Systems thinking is an area in health research that analyses the parts of a defined system and their connections in relation to the whole.**
- **Complex systems are characterised by different levels of variability, uncertainty and different levels of organisation that range from simple organisations within a system to highly complex ones. Complex adaptive systems are a particular type of complex organisation characterised by feedback – learning and self-adaptation lead to the emergence of new states with new properties.**
- **According to systems thinking approaches, health systems should be described in terms of their boundaries, agents, connections and drivers.**
- **If the definition of core drivers and boundaries is lacking at meso level, then the capacity for effective systems thinking is severely limited.**
- **Health interventions are one of the priority areas for systems thinking which can elucidate how an intervention:**

  (a) embeds within context and manifests itself in thinking and practice;
  (b) changes relationships
  (c) displaces existing activities (which may account in part for intervention effect); and
  (d) redistributes and transforms resources (material, informational, social, and cultural).

Systems thinking deliberately moves away from standard methods of identifying the cause and effects of interventions. It has adopted novel approaches to capture the complex nature of multi-directional, overlapping relationships, feedback loops, learning and compounding effects of multiple changes within the system.

Complex adaptive systems theory

Complex systems theory has arisen from two main schools of thought – general systems theory and cybernetics (See Appendix I for an overview of the work of key scholars in these fields). As a theory it provides a *model of reality*, not reality itself. However, it can have utility in solving particular everyday problems.

We can use systems theory to distinguish between different types of systems. Along a continuum, they can be classified as simple, complicated, complex (dynamic) and complex adaptive systems (summarised in Table 1).

In simple systems, elements of the system interact in one-to-one relationships producing predictable outcomes. Simple systems can be engineered and controlled. They are closed to and therefore not influenced by the external environment.

Complicated systems display some of the same characteristics of simple systems in that interactions between elements in the systems are predicable, although any one element of the system may interact with multiple other elements of the system. Relationships are still linear and outcomes are predictable. Generally speaking, 'complicated' refers to systems with sophisticated configurations but highly predictable behaviours (e.g. a car or a plane) – the whole can be *decomposed* into its parts and when reassembled will look and behave like the whole again. They are also closed to and therefore not influenced by the external environment.

Complex dynamic systems have two key characteristics, they *self-organise* without external control and exhibit *feedback* resulting in newly created, i.e. *emergent* (at times unforeseen), behaviours. *Complexity* is the dynamic property of the system; it results from the interactions between its parts. The more parts interact in a nonlinear way in a system the more complex it will be. Complex systems are also open, loosely bounded, influenced by their environment. Such *fuzzy boundaries* entail some arbitrariness in defining a system.

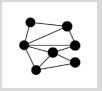
While any one system as a whole may be defined as a complex adaptive system, inevitably subunits are also complex adaptive systems in their own right. Thus any defined complex adaptive system has to be thought of as being simultaneously a subsystem of a larger system (or a suprasystem) and a suprasystem constituted by a number of subsystems (this is known in the literature as the *nested structure of systems*).

Complex adaptive systems (CAS) are special case of complex dynamic systems as they have elements (agents) that can learn and adapt their behaviours to changing environments. In the complex adaptive systems literature the elements of the system are referred to as agents. Complex dynamic and complex adaptive system behaviour is influenced by the *system's history*, i.e. influences that have resulted in the current state of a system have ongoing effects on future states.

The make-up of the complex and complex adaptive systems presents certain problems in terms of being able to understand, describe and analyse them. While simple and complicated systems lend themselves to cause-and-effect analysis, complex and complex adaptive systems require a mapping of relationships and drawing of inferences that may be theory based or drawn from multiple sources of knowledge. (See Appendix II on the Cynefin Framework (11) on understanding the function of CAS resulting from different strengths of relationships between the structure of its agents).

Understanding the differences between types of systems is often the clearest way to define a complex adaptive system. Table 1 summarises features of simple, complicated and complex systems and the language used in the literature to describe them.

Table 1: Comparing the terminologies and meanings of different types of systems

Types of Systems	Simple	Complicated	Complex	
	Mechanical systems		Complex (dynamic) systems	Complex adaptive systems
				
Structure of System	One-to-one relationships	One-to-many relationships	Many-to-many and system-to-system relationships (nested systems)	
				
Outcomes	Highly predictable	Mostly predictable	Alter with history and initial conditions Unpredictable/emergent Non-linear and feedback Complex - Chaotic	
	Linear			
Outcome Patterns	A change in *x* results in a proportional change in *y*		A change in *x* results in a disproportional change in *y*	Attractor patterns that may be appear chaotic
Control of System	*Engineered*		*Laws of nature*	*Social "laws".* No controlling agent *Purpose, goals and values* define *simple rules* for interactions
Properties of System			Self-organisation results in emergent behaviour Complexity of systems increases with the rise in # of agents	
Relationship to environment	Closed		Open – loosely bounded	
Relationship of components/agents				
Behaviour of components/agents	Cause and effect repeatable, predictable	Cause and effect are separated over time and space	Cause and effect only coherent in retrospect and are not repeatable	No cause and effect relationships are perceivable (might or might not exist)
Analysis	Cause and effect analysis (reductionism}		Structure: mapping Function: inference based on laws of nature	Structure: mapping Function: inference based on prior knowledge
Testing	Lab	Lab/Discrete event and or system dynamics modelling	Lab/field	Agent-based modelling Field trials
Generalizability	Yes	Yes	No	No

Complex adaptive systems theory: making sense of how complex systems work

Complex adaptive systems theory seeks to make sense of how complex systems, such as social systems and health systems operate and function. It seeks to define how, and why, an order exists within these systems, despite the highly interconnected and interdependent nature of relationships and the emergent nature of outcomes stemming from these relationships. Despite these features, complex adaptive systems sustain a high degree of order (only when they lose order do they shift into a purely chaotic state).

A healthcare system is a social system. Complex adaptive system theory describes social systems as emergent based on their common statements of *purpose, goals* and *values.* When a social system has clearly defined purpose, goals and values, and these are adhered to by all its agents, the system will be 'goal-delivering' (12-18). The larger and more open the system the more difficult it is to define, and the more difficult it is for leaders to galvanise its agents to adhere to its purpose, goal and values. Appendix III contains a case study of a complex adaptive system – the NUKA system – that has relatively well defined boundaries that demonstrates how this concept can be applied in a real world example. (See Appendix III: Case Study – the NUKA emergent health system).

In complex adaptive systems theory:

- Values: refers to the ideals and customs of a system toward which the people/agents have an effective regard. Values are concepts that transcend contexts. They are universal within the system (19).
- Having agreed *purpose, goals and values* defines the **driver** of the system; together they give rise to the "operational instructions" that coherently direct the interactions within a CAS. These are termed "*simple rules*" (20), and must not be contradictory.
- "Simple rules" reflect the core values of the systems. *Core values* are those that remain unchanged in a changing world. If internalised and adhered to by all agents it results in the "smooth running" of the system (18, 21-23).
- "*Simple rules*" provide the necessary "safe space/freedom" to adapt agents' behaviour under changing conditions. Adaptation is desirable; it fosters creativity and provides flexibility; it is the prerequisite for the emergence of the system and the achievement of its goals (also referred to as learning) (18, 21-23).

CAS activity results in patterned outcomes, based on purpose, goals and values within the *constraints of the local context*. These outcomes, while not necessarily intuitively obvious, are the result of the self-organising properties of a CAS, and overtime lead to "newly" emergent states e.g. while a call for controlling whooping cough through public health measures by a health department provides the goal, each local public health unit will implement it somewhat differently resulting in a unique outcome. The resulting outcomes, while somewhat different, are "*mutually agreeable*". These outcomes form a pattern that represents the system's adaptive abilities to achieve the desired overall outcome.

Importantly, goals, values and simple rules, and the way they play out within the system are unique to that system. They cannot be transferred from one place to another as the local conditions that resulted in the system outcome will be different, the reason why even proven innovations fail when transferred into a different context (24).

Key messages for policy

- **A health system should be viewed not only in terms of its component elements/agents (eg. human resources, financing, hospitals, clinics, technologies, etc.) but most importantly in terms of the interactions between the agents (25).**
- **There is little argument that health systems are complex, however, there is widespread disagreement as to whether they function as seamlessly integrated complex adaptive systems in accordance with complex adaptive systems theory.**

- Health systems, being composed of agents that can learn and change their behaviours in light of changing environments, have all of the defining features of a CAS.
- However there are observed difficulties for the health system to respond to changing demands (such as a change in the morbidity patterns) and in defining purpose, goals, values and central drivers.
- Complex adaptive systems cannot be controlled, the direction of their development can be guided and requires leadership that reinforces each organisation's *purpose, goals and values* and allows its agents to act "independently" within the boundaries of the organisation's *simple rules* (20, 26-30).

Question 1: How does the concept of a complex adaptive system apply to the Australian healthcare system?

Premise: That the concept of complex adaptive systems is applicable to the Australian healthcare system, and key characteristics can be identified

Systems thinking approaches

As noted above, we know little about the characteristics and dynamics of overall health care systems, and practically nothing of the key properties of health care systems as complex adaptive systems (CAS). However, there are plentiful examples of tools, methods and applied analysis for describing and understanding main components of health care systems, their properties and the effects of interventions, or events, on agents within the system.

Various disciplines have contributed to the applied approach of 'systems thinking' in health care. Many of these approaches have functional applications that could be applied (or are already in use) for assessing and planning health care. Here we review relevant contributions from six sectors: engineering, business, defence, computer sciences, public policy and geography. We give examples where applications have been used in Australia, or elsewhere in a way useful in the Australian context.

Systems approaches from engineering

Systems engineering focuses on how to design, operate and measure complex systems over their life cycles, and how to analyse and improve their efficiency, productivity, quality and safety. Even though each system is an integrated whole, systems engineering has developed methods for understanding complexity by decomposing subsystems, specialized structures and sub-functions (e.g. microsystems) (31). There are plentiful examples of the application of systems engineering to health care delivery; although it is more common in the US and Europe than in Australia. These methods include Plan-Do-Study-Act (PDSA), Situation-Background-Assessment-Recommendations (SBAR), stochastic modelling, House of Quality, and statistical process control charts based on the lean method of six sigma steps: (1) Identify needs; (2) Define requirements; (3) Specify performances; (4) Analyse and optimize; (5) Design, solve and improve; (6) Verify, test and report (31, 32). Systems engineering has been adopted in the US to provide recommendations for reducing the health care waste, and to improve its overall efficiency (33). An example of this approach is the initiative promoted by Johns Hopkins University Medical Faculty, Applied Physics Laboratory and the Whiting School of Engineering's Systems Institute to couple systems engineering principles and best practices with clinical expertise to improve understanding of the interactions among agents (clinicians, patients, families, and other stakeholders), processes (institutional, regulatory, professional ethics, etc.), and technology (medical devices and instrumentation) to formulate innovations and better patient outcomes (34).

Systems approaches from business, economics and knowledge management

Some of the more advanced analyses of human organisations as complex systems come from the business sector. Business intelligence uses qualitative and quantitative tools for explanatory and predictive modelling to drive decision making. Business analytics uses a number of techniques that significantly improve the capacity of traditional statistical techniques for data analysis under conditions of uncertainty, going beyond multivariate analysis and data mining to incorporate modelling, knowledge management, expert knowledge and artificial intelligence, and visualisation. Examples of their application in health care include Knowledge Discovery from Data (KDD), Expert-based Cooperative Analysis (EbCA), outcome management analysis or causality analysis using hybrid-based modelling (35, 36), and use of the lean approach to health logistics – on which there is an extensive literature (37). The quality improvement model (IHI-QI) developed by the Institute of Health Improvement in the US also incorporates systems thinking and system network analysis,

theory of knowledge, organizational psychology and system dynamics. The IHI-IQ model and the lean method have recently been applied to the assessment of innovation in health care (38).

Hargreaves has reviewed the methods and techniques used for evaluating system change in health care(39). She provides a clear differentiation between complicated and complex organisations. According to this author computer simulation models of stocks, flows, and feedback; causality models; social network analysis, and interrupted time-series analyses are useful techniques for the analysis of complicated systems, whilst Geographic Information Systems (GIS), agent-based modelling, time-trend analysis and adaptive learning systems, backward engineering or retrospective evaluation are suitable for the analysis of complex systems (39).

Hybrid techniques derived from business intelligence and analytics were applied first in health economics in the health care sector and then applied to system analysis in health care. Business analytics combined with visualisation tools and mapping may be particularly useful for improving the analysis of large volumes of data for policy and planning. An example of this approach is the development of an integrated information system in the Northern Health region in British Columbia (Canada) to guide planning in this health care system (40).

Systems approaches to knowledge transfer have drawn on management thinking about complexity to identify the conditions under which change is likely in health organizations (41). Best and Holmes (2010) have shifted the analysis of knowledge transfer from mechanical models of diffusion and dissemination to build implementation models incorporating the interactions of evidence and knowledge, networks and communications and leadership (42).

Systems approaches from defence, aviation and other high-risk sectors

High risk industries and sectors such as commercial aviation, the oil and gas industry and defence have developed most rigorous methods to measure and improve safety performance. These have provided models for improving performance in health care (43). The High-Reliability Organisation (HRO) is a safety operational technology developed for dangerous and complex environments where an error can have fatal consequences, such as aviation, nuclear power plants, or fighting wildfires. This approach was developed for the US Navy's nuclear-propulsion program, for contexts where agents (operators and users) "don't have the luxury of learning from their mistakes" (44). It develops a zero-defect culture based on the recognition that highly technical operations depend on the interaction of systems, subsystems, agents and contexts. These complicated/complex interactions give rise to deviations that must be corrected before they become fatal. Winnefeld and colleagues enumerate 6 principles of HROs: integrity, depth of knowledge, procedural compliance, forceful backup, a questioning attitude, and formality in communications. The US Agency for Healthcare Research and Quality (AHRQ) has released operational advice for the transfer of this approach to hospital management (45). The National Patient Safety Foundation (NPSF) has incorporated the HRO approach into their guidelines to improve "Root cause analyses" (RCAs) at hospitals for exploring safety events (46). SWARMing is an approach based in techniques from NASA (RCAs) and the US Veterans Administration, which uses triage cards; and has been applied for system improvement by reducing adverse events in the UK and the US (47). WHO has developed a similar conceptual framework for incident reporting within the International Reporting and Learning Systems (RLS) Community of Practice. This conceptualises adverse events as results of a complex interaction of agents and processes. Reduction requires a comprehensive approach to this systems context. (48).

Another relevant contribution from the military sector, drawing on experiences of aviation safety, is the analysis of the agents operating in a system as functional teams. The US Department of Defense (DoD) and the AHRQ developed TeamSTEPPS, a teamwork model that offers a powerful solution to improving collaboration and communication within health care settings (meso-level organisations). These teamwork approaches have been one of the key initiatives within patient safety that can transform the culture within

health care. Teams are defined by the TeamSTEPPS model as "two or more people who interact dynamically, interdependently, and adaptively toward a common, shared and valued goal, have specific roles or functions, and have a time-limited membership". A recent review of the implementation of this systems approach in large health systems found 'measurable improvements in teamwork, communication, and patient satisfaction' and a decrease in errors and averse outcomes. (49).

Systems approaches from computer sciences

Computer sciences have played a decisive role in the development of many of the advances in the different sectors mentioned in this section. Since the 1960s decision support systems (DSS) and toolkits were developed in defence, business, policy and education. The different approaches were summarised in the 1980s in a typology of DSS that included: 1) *File drawer systems* that provide access to data items; 2) *Data analysis systems* that support the manipulation of data by computerized tools tailored to a specific task and setting or by more general tools and operators; 3) *Analysis information systems* that provide access to a series of decision-oriented databases and small models; 3) *Accounting and financial models* that calculate the consequences of possible actions; 4) *Representational models* that estimate the consequences of actions on the basis of simulation models; 5) *Optimization models* that provide guidelines for action by generating an optimal solution consistent with a series of constraints; and 6) *Suggestion models* that perform the logical processing leading to a specific suggested decision for a fairly structured or well-understood task (50). DSS have had a huge impact in health care. They have played an essential role in the development of knowledge-to-action strategies in systems thinking (see below), by incorporating new tools to model and data-oriented systems, management expert systems, multidimensional data analysis, query and reporting tools, online analytical processing (OLAP), Business Intelligence, group DSS, conferencing and groupware, document management, spatial DSS and Executive Information Systems (50).

Simulation models can incorporate multiple levels of complex interactions. The Prevention Impacts Simulation Model (PRISM) compares different interventions for reducing cardiovascular disease risks in a controlled and systematic way). The comparison included the effects of interventions across diverse policy domains – including clinical, mental health and behavioural, to start to represent the interactions characteristic of complex systems in real life (51). In Australia, simulation modelling has been used to test the combined effects of multiple interventions aimed at suicide prevention. This multi-scale dynamic model mapped the structure of relationships between agents and events, encompassing both feedback and delays. The model was used to enable desktop experimentation of policy scenarios. (52)

Marshall and colleagues provide a concise summary of the most commonly applied dynamic modelling techniques as part of their work within the International Society for Pharmacoeconomics and Outcomes Research. Systems dynamics (that models feedback, accumulations stocks, flows, and time delays), discrete event simulation (that models queuing processes) and agent-based modelling (that models agency, dynamics, and structure) integrate techniques from the above listed disciplines and have found widespread application. The use of these models in healthcare has recently accelerated, although mostly for operations and logistics in hospital settings such as scheduling, queuing and transportation. (53)

Systems approaches from public policy

Developments in public education and public policy deserve special attention. The development of Decision Support Systems and knowledge-to-action strategies in public policy have also provided models for evidence-informed health care policy. Microsimulation techniques have been increasingly adopted whereby complex real-life events are simulated and the impact of policy change on the individuals that make up the system are predicted.

An example of the potential applicability of new policy approaches to health care is Marine Ecosystem-based Management (MEBM). It provides a guided approach for understanding complex processes and for designing knowledge-to-action policy from a holistic, integrated approach to manage ecosystems, including human (54). It is based on three principles: salience, credibility and legitimacy. This approach provides tools

to understand trade-offs to be made between ecological, economic and social sustainability criteria, the diversity of cross-sectoral perspectives, values, stakes, and the specificity of each individual situation in determining the outcomes of these trade-offs. The challenge of designing effective systems for linking knowledge and action—systems that produce information that is perceived to be salient, credible, and legitimate—is complicated if a system is perceived to be seriously lacking on any one of these dimensions, its likelihood of producing influential information falls significantly.

The Interactive Systems Framework (ISF) for Dissemination and Implementation is a practical application of the knowledge-to-action framework to health care policy. It has been developed to address the "how to" gap that exists between scientifically determining what works, and moving that knowledge into the field for the benefit of the public, particularly in prevention strategies. It has been applied by the US Centers for Disease Control and Prevention (CDC) for designing prevention policies in highly complex areas. The ISF includes activities or functions that are carried out by a variety of individuals in many different roles that make dissemination and implementation possible. These activities include: (1) distillation (Prevention Synthesis and Translation System—PSTS), (2) support (Prevention Support System—PSS), and (3) delivery (Prevention Delivery System—PDS). By understanding the functions of these three systems and how they interact, stakeholders (organizations, funders, researchers, and practitioners) can communicate better and work together to disseminate information and more effectively implement prevention innovations. CDC has developed the Rapid Synthesis and Translation Process (RSTP), using the exchange model of knowledge transfer in the context of one of the ISF systems: the Prevention Synthesis and Translation System. It has applied this to the design of health and integrated polices in violence (55) and suicide (56). There are other approaches to rapid synthesis such as the Robert Wood Johnson Foundation's (2009) six-step process in their Synthesis Project (http://rwjf.org/pr/synthesisabout.jsp); or the exchange model adopted by the Canadian Health Services Research Foundation to improve the evidence based decision making capacity of policy makers (55).

Realist evaluation provides an empirical evaluation approach for the study and understanding of programmes and policies. This technique assumes that knowledge is a social and historical product and that programs are embedded in social systems. This is an increasingly popular approach in health systems research seeking to understand why complex interventions work. Realist evaluation identifies the mechanisms, contexts and the conditions enabling (or blocking) the transferability of interventions (57). The guides for quality and reporting standards and training materials for realistic evaluation in health care are currently under development (RAMESES project) (57).

Systems approaches from geography and context analysis

The boundaries of a system, its subsystems and clustered systems and the relationship with neighbouring systems need to be formally defined and described before starting any system analysis. Paradoxically, the majority of system literature in health care does not provide enough –if any- information on the geographical location and spatial characteristics of the systems analysed. Geographical information systems can be to represent and to understand the distribution of agents, their connections and spatial relationships (58). Although relatively new, health geography has gained major attention in the last 15 years and has been recently strengthened by the development of context analysis. Context refers to the totality of environmental circumstances that comprise the milieu of human life. It has provided an integrative framework to identify policy goals related to personal outcomes and to other indicators in healthcare. The evidence gathered in observational/ecological studies in local areas together with the analysis of big data, service use and costs have enabled analysis of care in a systems contexts (59, 60). Atlases of health care provide decision support tools that combine context analysis of jurisdiction boundaries, agents operating in a system, service delivery and network analysis. A growing number of examples of the use of these tools for health system analysis have been published in Canada (40, 61); and Europe (62, 63). For example, the

mapping of food deserts, a geographical area devoid of access to (healthy) food has influenced outlet licencing policy. (64)

While many of these approaches use some of the language of complex adaptive systems analysis, there are few examples of empirical or operational analysis that uses the full CAS framework. However, each of the approaches summarized above – and many more – are making profitable use of systems thinking to give a better understanding, and develop analytical and policy tools, to understand health systems. At their strongest, many of the tools and methods listed above have culminated in two most commonly applied systems thinking tools for health care planning – mapping and dynamic system modelling.

Key messages for policy

- **Little research has been conducted that use a full complex adaptive systems framework to analyse key properties of the Australian health care system as a whole (CAS).**
- **There are plentiful examples of tools, methods and applied analysis from allied sectors that can be applied for describing and understanding main components of health care systems; including from engineering, business, defence, aviation and other high risk sectors; computer science; public policy and geography.**
- **Key applications of these methods include: risk management, predictive modelling, life-cycle mapping, knowledge-to-action frameworks, social and system network mapping, decision support systems, root cause analysis and safety operational technology.**
- **Few examples of analysis techniques above use the full complex adaptive systems framework, however, each of the approaches summarized above – and many more – are making profitable use of systems thinking to give a better understanding, and develop analytical and policy tools, to understand health systems.**

Complex adaptive systems theory

Based on the principles that define organisations as complex adaptive systems in CAS theory the Australian health system has to be considered to be a CAS. It has:

- agents – health ministers, health bureaucracy, health financing organisations, hospitals and community offices, the various health professionals, health user groups and individuals (note: agents in systems terms can be people, organisations, institutions etc), and
- these agents interact and through these interactions, *learn* – in consultation, within a hospital, between central bureaucracies and local health service units etc.

However, the "operating principles" – the framework that defines the boundaries within which agents are expected to act – are not readily evident. Tacitly:

- *purpose* – may be loosely described as helping people with illnesses
- *goals* – are most clearly defined as providing universal healthcare
- *values* – are not succinctly stated and evident to all agents
- *simple rules* – are not overtly defined.

As the *purpose, goals, values* and *simple rules* of the Australian health system are not clearly evident, *the system as a whole has no identifiable unifying driver*. The lack of a unifying driver makes the Australian health system look more like a "conglomeration of discrete units", colloquially expressed as "a fragmented health system".

Subsystems of the Australian health system

More commonly the health system is discussed in terms of it subunits, e.g. primary care, mental health, the hospital, public health etc. As these subunits are CAS in their own right they can be analysed according to the same principles. It is outside the scope of this review to describe individual units, sub-units, sub-sub-units etc, however, it is clear that the agents of small functional units like an intensive care unit (65) at large have a clear but *tacit* understanding of their *purpose, goals and values* and understand the *simple rules* that guide their actions and behaviours.

Aligning drivers

The driver of a system provides the focal and unifying reference point for all agents in the system. While it is acknowledged that subsystems require individual drivers to function, it is critical that for a system with many subsystems to function seamlessly as a whole, subsystems need to align their drivers with the overarching one that defines the whole system.

Current Australian health system most likely does not function as a CAS

The general observation that the Australian health system is fragmented and poorly integrated leads to the conclusion that – as a whole – while having the structure of a CAS it does *not function* as a CAS. Using a CAS-analysis approach Sturmberg, O'Halloran and Martin (66, 67) attempted to describe the Australian health system in relation to the criteria of a "truly complex adaptive" system in accordance with complex adaptive systems theory. The findings are represented in the health vortex (See: Figure 2) – the vortex entailing the notion of the system's focus and overall function; rising from the apex are the local primary care services and hospital services, community level services, regional health services and at the top the policy level.

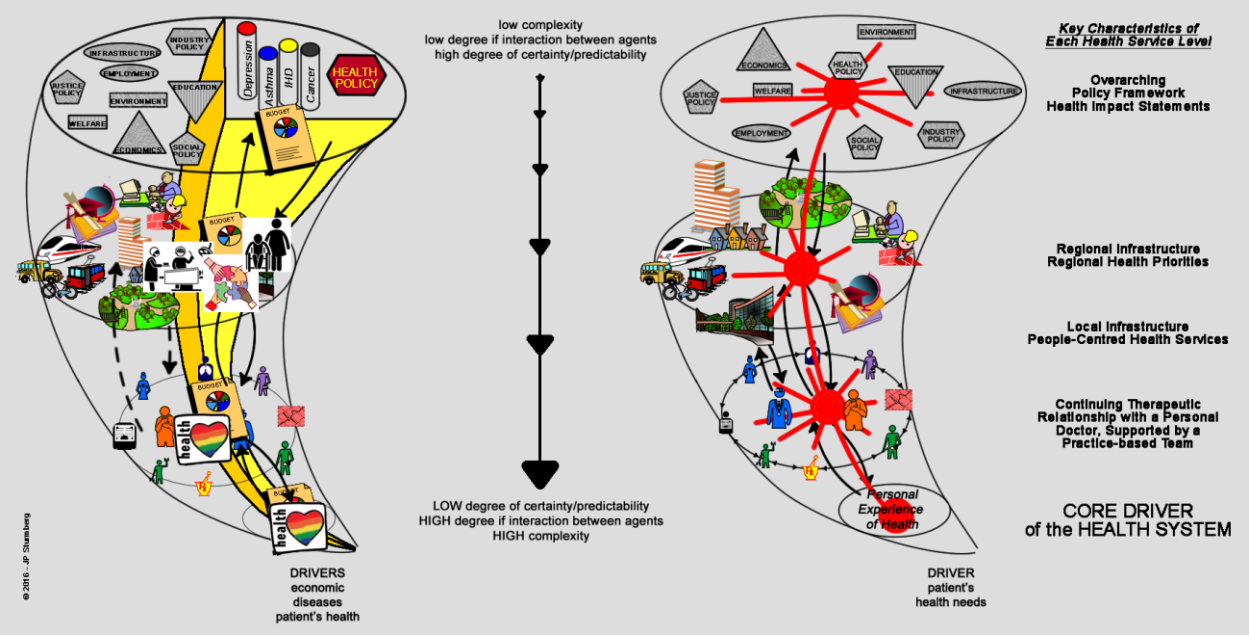


Figure 2: Application of vortex model to the Australian health system

The left side of Figure 2 shows the fragmentation within the various organisational levels in the Australian healthcare system (explored further in response to Question 2, below) resulting from differences in drivers of subsystem units like: focus on patient's health experience at the primary care level, disease focus in hospitals, focus on public health priorities at the community services level, and a focus on global disease and health budgets at the policy level. The vortex representation on the right shows a *seamlessly integrated* complex adaptive health system that assumes as its overarching system driver the "person's health needs". As an overarching driver, levels across and within the health system would all align their activities towards

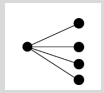
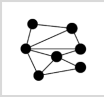
achieving the system's "common goal", but would do so autonomously in their own ways (subsystems determine their own drivers).

The Australian health system incorporates subsystems of a simple, complicated, complex and complex adaptive nature and is illustrated in Table 2.

Key messages for policy

- **Understanding the health system as an integrated CAS requires agreement of an overarching driver that needs to be brought and kept in the forefront of all health system agents.**
- **As most problems confronting health policy makers relate to subsystem issues, policy makers should consider any problem in the context of the whole system.**
- **Most adapted solutions for the problem of a subsystem will emerge from helping all agents of that system to align their drivers with those of the whole system (addressing the interconnected nature of system structure and function).**

Table 2: Simple, complicated, complex and complex adaptive subsystems in the Australian health system

Types of Systems	Simple	Complicated	Complex	
	Mechanical systems		Complex (dynamic) systems	Complex adaptive systems
Examples in community health care	Flu vacciantion	Managing a 2nd degree burn	Community Care for frail elderly, linking care domains	Collaboration in GP clinic Multimorbidity management
Examples in hospital health care	Laboratory testing	Hip replacement surgery	Bed management in a hospital	Intensive care unit Acute psychiatric unit Staff management of a hospital
Examples in health sub-system		Protocols, e.g. handwashing policy		Mental health Managing an epidemic Managing a natural disaster Health financing
Structure of System	One-to-one relationships  e.g. nurse giving Flu shot	One-to-many relationships  e.g. surgeon managing a theatre team e.g. nurse unit manager ensuring staff records every patient incidents regardless how trivial	Many-to-many relationships System-to-system relationships (nested systems)  Subsystems can have simple, complicated, and complex components e.g. the value of services listed in the MBS (simple) however the fees charged by individual doctors to different patients in their practice is highly variable and depends on many factors (complex adaptive)	
Outcomes	Linear e.g. measured as percentage of eligible population being vaccinated	Mostly predictable e.g. measured as number and type of in theatre complications	Alter with history and initial conditions Unpredictable/emergent e.g. contextual description of the SES characteristics of population groups, the detailed description of delivery of an intervention and the observed outcomes (e.g. harm reduction of illicit drug use)	
	Linear		Non-linear and feedback Complex – Chaotic	
Generalizability	Yes	Yes	No	No

Question 2: In considering the Australian healthcare system as a CAS, what agents exist at a macro, meso, micro and nano level and what are the relationships between them?

Premise: That agencies in the Australian healthcare system can be mapped in terms of levels and inter-relationships

Systems thinking approaches

Health systems operate in fuzzy boundaries with other systems and within boundaries set by geography and levels of organisation. Wilson et al. (1995) stratified decision-making levels within health services, identifying "micro" (between patient and clinician); "meso" (community level, including healthcare services) and "macro" (governmental) (68). To enable the study of health systems at the level of service delivery, the level at which users experience health care, "micro" should refer to "individual service" and "nano" to the individual patients.

Berwick's alternative scheme for conceptualising decision-making layers takes a more three dimensional approach. It defines microsystems as the building blocks of a health-care delivery system where direct interaction occurs between the patient and provider (69). Moving outward from this microsystem, the delivery system encompasses more stakeholders at the mesosystem level (e.g., divisions of general internal medicine, surgery, or nursing) and further out at the macrosystem level (e.g., hospital administrators, or government regulators and policymakers) (31, 70).

This schema can be complemented by the Donabedian model as Tansella and Thornicroft (1998) have done in the mental health care context. The model adds geographic levels (country, local area, individual) to form a matrix, enabling a more holistic and systemic analysis of integrated care across the different components of the system (71).

System levels and agents in applied analysis

Deriving useful learning means carrying out a thorough analysis involving quantitative and qualitative methods with a range of different stakeholders (e.g. researchers, patients and healthcare professionals), at different levels of the system (macro to micro), and considering the context of the system. A significant proportion of the available literature in health systems and planning refers only to a limited number of agents at organisational levels – and rarely are these analyses combined with contextual and spatial analysis. We return to the building blocks of systems analysis to discuss these deficits in the literature and give some examples where they have been used.

- **Boundaries.** We see the start of the use of systems approaches to analyse spatial contexts and the boundaries of local systems. This has been undertaken by several health atlas projects, mainly at local level (eg Fernandez et al, 2016 (72)). The recently published *Australian Atlas of Healthcare Variation* (73), identifies areas of high variation in a series of key care performance indicators. It describes for the first time health care provision across Australia and constitutes a major source of information on service availability and care variability across the health system. It also provides a detailed description of several subsystems and its agents.
- **Agents.** Systems approaches to health care assessment and planning usually define agents of interest in the system, but rarely specifically stratify them according to system levels. In part, this is likely to be a deliberate decision in recognition of the blurred lines of connectivity and location of action in a complex system. 'Locating' an agent within a system level remains a conceptual exercise to a degree, but a useful one all the same. It can assist in identifying key agents at the stage of mapping a system, reducing the likelihood of 'missing' important agents. In Appendix IV we summarise different agents that have influence within the system and stratify them according to the system level where they exert direct influence and their interest within the system. For example, on the macro level, policy makers in government, large firms, lobby groups and non-government

organisations exert influence. On the meso level, community, state and federal public institution in various sectors plan and coordinate services. On the micro level health care services are delivered and service providers interact directly with users and each user interacts with its direct social circle comprising family and friends. On the nano level we see the individual.

- **Connections.** Social network analysis is emerging as one of the more popular tools for identifying connections between agents at different decision making levels for assessing and planning health care in Australia. For example, Nancarrow and colleagues mapped service integration for primary healthcare patients in the Lismore GP superclinic. They defined 'integration' in terms of the connections between agents at micro, meso and macro levels within the system, and assessed actual connections by means of a social network analysis (Unicet 6) of patient referrals. (74). Systems modelling has also been used in recent years to better understand the connections between agents and use information about what is known about how agents react to environmental changes to predict outcomes. Latkin et al. modelled HIV-related behaviours that influence HIV prevention and detection on macro, meso and micro levels (75) and Maddox et al have examined social network and their impact on tobacco use. (76, 77). Sadsad and McDonnell (2014) outline steps for creating multiscale models on the example of stock levels in health services and include the determination of systems levels as part of the process.(8) Predictive risk modelling has also become a widely utilised method to predict future health service utilisation, although the majority of models currently applied for this purpose do not take a systems thinking approach. (78)
- **Drivers.** There have been attempts to formally state the objectives and drivers of Australian health care. In 2009 the Australian Government Department of Health and Ageing released a strategy "with the direct intention of reaching the goal of Australia being the healthiest nation by 2020". Following this, health promotion and prevention may be regarded as priority goals in our system. The 7 strategic directions included shared-responsibility, community engagement, the need to influence markets and develop coherent policies as well as to "refocus primary care towards health prevention" (3). The national health priority areas were focused in 9 health chronic conditions. The concept of person centred health care was notable by its absence. On the other hand a number of subsystems such as mental health have re-oriented their drivers towards person-centred care both at national level and in several local areas.

In his integrative approach, Frenk emphasises that the analysis of systems dynamics is not possible if we do not collect the basic information required on agents, connections, boundaries and drivers (79). Key authors of this report are currently undertaking a program of analysis that brings together each of these elements in an analysis of agents at various system levels in mental health. The "Integrated Atlas of Local Mental Health" carried out by the University of Sydney has mapped the functional teams operating at the micro-level in several health districts (PHNs/LHDs) in metropolitan Sydney and in the Far West in NSW (72). Service availability, placement capacity and workforce capacity were mapped and an analysis accessibility/service gaps/unmet needs in the local population undertaken. In the near future this information will be completed with the social network analysis of the connections of the different agents operating at micro, meso and macro level in the local system.

Key messages for policy

- **Decision-making levels within health services can be stratified into the following: "nano" (individual); "micro" (between patient and clinician); "meso" (community level, including healthcare services) and "macro" (governmental).**
- **Schemes using these levels can be complemented by the Donabedian model adding geographic levels (country, local area, individual) to form a matrix, enabling a more holistic and systemic analysis.**

- **Systems approaches to health care assessment and planning usually define agents of interest in the system, but rarely specifically stratify them according to system levels. In part, this is likely to be a deliberate decision in recognition of the complex nature connectivity and location of action in a complex system.**
- **(Social) network analysis and systems modelling techniques (multi-scale, dynamic, multi-level) are increasingly being used to analyse connections between agents in a complex system.**

Complex adaptive systems theory

The question presupposes that the Australian health system is organised in functional units (subsystems) at distinct organisational levels.

Organisational levels

Organisational theory views organisations as multi-level structures with macro, meso, micro and nano level structures and functions (the roles and responsibilities at each level are detailed separately in Appendix IV). In the context of the health system we typically think of:

- the macro level as dealing with policy and governance issues;
- the meso level managing regional health, community, social and infrastructure services;
- The micro level providing local/individual care delivery in the local community; and
- the nano level describing personal/organismic health and disease characteristics/functions (80).

This conceptualisation of the health system comprising multi-level structures is consistent with the complexity notion of nested systems in CAS theory. Each level will have its own unique structures and activities with well-defined roles and sets of well-defined rules. Whilst many of these levels/subsystems may appear to work effectively when viewed in isolation, it is critically important to ensure that they seamlessly contribute to the integrated function of the 'whole system'. Only when agents and their various subsystems act in accordance, with the system as a whole will it be 'seamlessly goal-delivering'.

There is a wide range of agents in the system with diverse interests in the Australian health system (See Appendix IV, Table 4 for some examples listed according to system level). Most notably their focus is often limited and self-serving e.g. at the macro level a health minister has to mediate justifiable health delivery demands against resource concerns, and in making those decisions is lobbied to act in the interest of vested stakeholders, be it industry interests, citizens lobby groups or other non-government organisations.

Links across system level – the example of food regulation

There are understandable constraints on agents at any system level in taking a 'whole of systems' perspective, i.e. one that works coherently to achieve common purpose, goals and values. This is because:

1) Subsystems may adopt purpose goals and values out of alignment, or even divorced from those of the whole system. As described above, the Australian health system as a whole has no identifiable unifying driver, making the system more like a 'conglomeration of discrete units'. Thus even if one agent may act in accordance with the rules of their own subsystem, these may not contribute to a common goal-orientation of the whole system.
2) Due to the systems highly distributed network nature, it may not be immediately clear, or devisable, what course of action will be most promising to lead to the desired outcomes in any another part of the system or for the system as a whole.

An illustrative example might be an agent on the macro level – a politician or senior bureaucrat responsible for food industry regulation. The prevailing "whole of government" perspective may be reduced to short

term budgetary impacts, rather than consequences of regulation changes (e.g. limits on salt and sugar content in foods) throughout the entire system.

This example alludes to "whole of system dynamics" e.g. changes to food regulation (a macro level activity) will interfere with the status quo of food industry economics (meso level) (people employed, cost of inputs, profit margins, taxes paid), the cost of foods available to consumers, but also the potential cost savings to the health system due to better health of individuals and the community. The latter though, will have economic implications to private sector health service providers. The potential need for fewer health services affects health professional education providers and potentially affects the social service system should this result in greater unemployment of health professionals in the community. At the nano level, community education about healthier food choices might lead to a greater demand for healthier food, thus providing additional incentives for food producers to change their production processes and product ranges. People might have to rebalance their budgets; some higher spending on food may be offset against less spending on health services. In addition, changes in food choices at the nano-level require adaptation in taste and the acquisition of additional cooking skills.

A core problem for the Australian health system is its fragmented nature. This has arisen from the lack of well-defined and promoted common goals, values, simple rules and thus drivers. Consequently, the Australian health care system is unpredictable. Mapping, modelling and field trial methodologies provide good starting points to understand these multiple subsystems of the health system.

Key messages for policy

- **Problems arising in any domain of the health system have implications across all organisational levels.**
- **Strong links between and across organisational levels increase the robustness and adaptability of the system.**
- **The fragmented nature of the Australian health system makes it difficult to act with a 'whole of system' perspective because:**
    - **Values, goals and drivers of different sub-systems are not aligned – or may even conflict**
    - **It is difficult to derive the potential influence that action in one part of the system may have on other parts of the system.**
- **System mapping and modelling are group learning tools that may be applied**
    - **to advance whole of system thinking in the absence of common drivers and**
    - **to work collaboratively towards defining mutually agreeable purposes, goals, values and simple rules.**

Question 3: In considering the Australian healthcare system as a complex adaptive system, where do consumers fit and what are their relationships with other agents within the system?

Premise: That the consumer has a place in a complex adaptive systems framework.

Systems thinking approaches

Based on the available evidence, we cannot determine whether the Australian health system asserts all properties of an integrated goal-oriented complex adaptive system. However, it is unquestionable that consumers are key agents of the Australian health system. Here, we refer to 'users' of the system, rather than 'consumers' encompassing not just patients receiving episodes of care, but individuals in various roles within the whole system.

Users are present in the system in many different roles, as patients, family members of patients, payer, advocates, voters and citizens; and individuals can wear multiple hats simultaneously. In such situations they are frequently balancing competing interests. These different roles bring different but overlapping relationships with the other agents. Users 'learn' about the system from experiencing it themselves. They form views about other agents from hearing about the experiences of others and from information supplied by more or less credible sources including their health care providers and the media. Other agents, such as doctors, health care managers, health insurers seek to modify the behaviour of users. Users' response to these interactions depend on the sum of those interactions but also broader influences such as their personal, social or financial situation, social, political or religious settings and particularly their prior experience of care. User responses to similar interactions therefore may vary depending on the influence of other factors.

Probably one of the most critical factors for users is the information imbalance in health care decision-making. Medical care is becoming increasingly complex, and the impacts of different diagnostic and treatment technologies less straight forward. For example, our ability to detect early precursors or changes of conditions such as dementia and other neurodegenerative conditions without being able determine the specific implications for the individual introduces a new dimension of uncertainty for the patient. Similarly, treatments may not offer cure but small increases in survival at the expense of significant side-effects, the need for ongoing therapy or loss in quality of life. It is very difficult for an individual patient and their family to understand the full implications and they are reliant on the expertise of the treating clinician to interpret this. Understanding and interpretation is even more complex when the individual has multiple conditions.

There is widespread agreement that users should be engaged in health care decision making. The spectrum of user involvement will be as multiple as the number of relationships they have within the system. However, if we accept the inherent characteristics of agents in complex adaptive systems, particularly that in response to their multiple roles and competing interests, agents tend to adapt to each other's behaviours, and also that agents are intelligent and learn from their interactions, then it points us to some different models of interaction.

The growing interest in involving the public in decisions about healthcare provision inspired the development of 'citizen juries' to identify and bring community values – and ownership – into health services. This could be a representative way of providing input into a complex adaptive health system design. This model was adopted for health care reform in the US (NIH Consensus Development Program) (81) and in Canada where consensus and state-of-the-science statements are prepared by independent panels of health professionals and public representatives. Citizens' juries, whose members were randomly selected from the electoral roll (rather than derived from user interest groups), were trialled in Western Australia a decade ago (82) and recently with the National Disability Insurance Scheme (NDIS).

Other key approaches to user involvement in the change of the health system is the concept of co-design and co-production. In practice, every day we make decisions intend to influence the design and operation of the health care system. As all agents in complex systems learn and change as a result of their interaction, then the concept of co-production has inherent attractions. A 2015 update reviewing areas in which user representative input has been influential in health policy and program decisions identified 13 areas (83):

1) identifying consumer issues that needed to be addressed in policy and program design;
2) improving the design and targeting of health communication strategies;
3) influencing the content of medical education and training programs;
4) balancing the interests of industry sectors through presenting the consumer perspective on health program resources and materials;
5) increasing the effectiveness of existing programs through improving access and targeting strategies;
6) influencing reporting requirements to ensure a consumer perspective is included and available to influence government decision making;
7) raising the profile of existing programs with key bodies to gain their support and endorsement;
8) advocating for health literacy strategies to empower consumers;
9) influencing the content of key government health policies such as the National Medicines Policy;
10) contributing to a cultural shift to broader views on consumer participation in health policy and program development;
11) influencing governance arrangements to ensure ongoing consumer input throughout an organisation;
12) changing the rhetoric and terminology of health policies and communications to reflect consumer experience; and,
13) achieving improvements in transparency of committee decision making processes.

Finally, collaborative care, self-support and peer-support are low-intensity complex interventions that require a system approach for its design, evaluation, review and implementation (84) (85) Community-led interventions have been implemented in Australia in some areas such as palliative care. LifeCircle conducts a mentoring program in NSW, in which volunteer mentors provide support exclusively to primary carers of terminally-ill patients, helping them to gather a support team and avoid burn-out, apart from other community led programs in palliative care (86).

Key messages for policy

- **Users/consumers are key agents of the Australian health system.**
- **Users are present in the system in many different roles, as patients, family members of patients, payers, advocates, voters and citizens; and individuals can wear multiple hats simultaneously. In such situations they are frequently balancing competing interests.**
- **Users' responses to interactions with other agents and events within the system depend on the combined weight of those interactions, but also broader influences such as their personal social or financial situation, social, political or religious settings and particularly their prior experience of care.**
- **User responses to similar interactions/interventions therefore may vary depending on the influence of other factors.**
- **Probably one of the most critical factors for users is the information imbalance in health care decision making, particularly in light of increasingly complex diagnostic and treatment pathways.**

Complex adaptive systems theory

Agents within the health system include not only institutions and organisations but also the whole population:

- as patients, with specific needs requiring care;
- as users, with expectations about the way in which they will be treated;
- as taxpayers/service purchasers and therefore as the ultimate source of financing;
- as citizens who may demand access to care as a right; and most importantly,
- as co-producers of health through care seeking, compliance with treatment, and behaviours that may promote or harm one's own health or the health of others.

Users have different patterns of interacting with other agents of the health system at large. Users may be involved with the system of primary care, prevention and health promotion, episodic treatment or acute treatment. Only around 3.2% of users require secondary care and only 0.8% require resource intense tertiary care in any given period, so users in our system should be conceptualised more broadly than patients or users of certain services (87-89) (See Figure **3**).

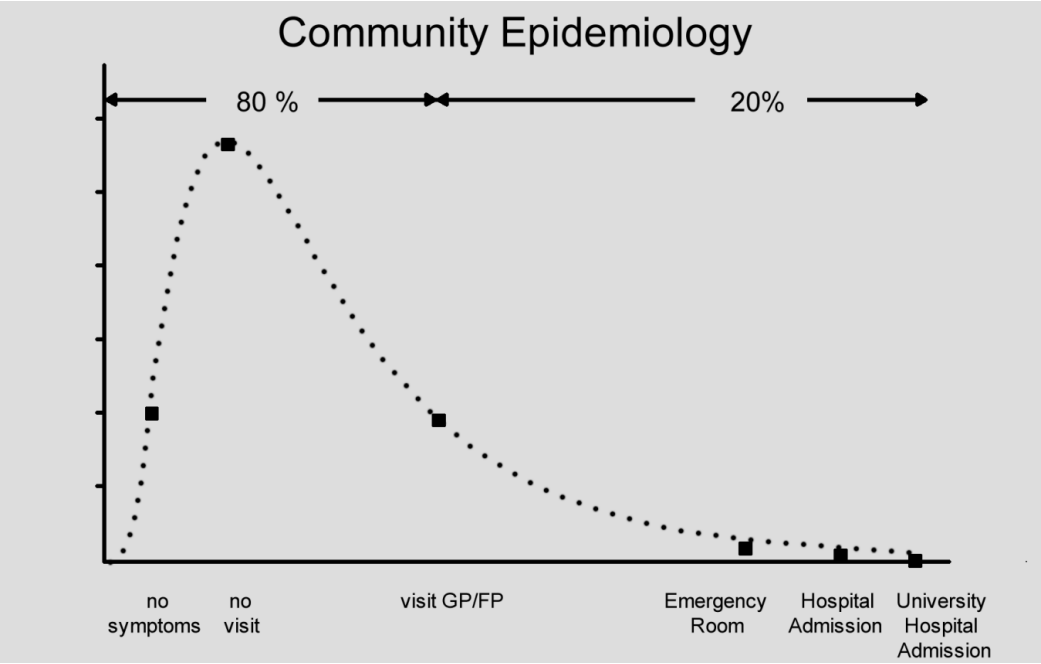


Figure 3: Distribution of health service use amongst 'users'

Users are co-contributors to the health system

Taking a whole of system perspective, users (should) play a key role in determining the purpose and goals of a system.

The case study presented in Appendix III – the NUKA system illustrates one example of how users can contribute to defining the values, goals, purpose and thus driver of a health system. In that example a national leadership (the United States Congress) legislated to create a geographically distinct subsystem for Indigenous Americans (Alaskans). Users working within this relatively closed subsystem of the wider American national and state health systems, were able to decide that they wanted a *person-centred* health service that offered (*purpose and goals*):

- relationships with primary care providers
- being treated with courtesy, respect and cultural understanding, and
- access to care when needed

The community determined the vision of their health service (*values*). It should:

- contribute to the community's physical, mental, emotional and spiritual wellness
- collaborate with the Native Community to achieve wellness through health and related services
- shared responsibility, commit to quality and family wellness.
- listen to people's feedback and understand their needs AND explain the changes being made in response to their feedback AND then communicate the organisation's successes in delivering what the community asked of it

As the example of the NUKA subsystem suggests, full engagement of users is essential to achieve a user/patient-centred health system. But there are challenges in this approach, particularly in a system that is fragmented, with a multicultural population, such as the Australian or broader US health system.

Engaging users in the design of health systems

Various approaches to increasing user involvement have been suggested in the literature, including:

- 'Citizen juries' as a way of providing public input into a complex adaptive health system design(90). User consultation often will allude to non-health-professional aspects that contribute to their health and health problems like social, housing, education, work and environment etc. issues and needs to be considered in the re-design of the system.
- Organisational level multi-stakeholder involvement – locating of citizens at the centre of the system surrounded by service delivery organisations and creating forums for joint decision making at organisational levels (91). This design offers the greatest likelihood of achieving a truly responsive, i.e. adaptive, health system; what happens at the higher levels is controlled by what happens at the lower levels (the effect of bottom-up emergence).
- Centralised user forums, such as the Australian Consumer Health Forum that acts a gateway for participation as well as lobby group for users at multiple system levels.

Key messages for policy

- **Agents within the health system include not only institutions and organisations but also the whole population (and multiple population sub-sets).**
- **Complex adaptive system theory recognises that while individual-level agents will have a set of – potentially – wide-ranging properties, they will bring certain ones – autonomously – to the forefront depending on context, and learn and adapt their behaviour accordingly.**
- **Full engagement of users is essential to achieve a user/patient-centred health system. But there are challenges in this approach, particularly in a system that is fragmented. It requires leadership committed to engaging all involved in the process of defining purpose, goals, values and simple rules and reinforcing these. Various approaches to increasing user involvement have been suggested in the literature, including: citizen's juries, organisational level multi-stakeholder involvement, and centralised user forums.**
- **Taking a whole of system perspective, users (should) play a key role in determining the purpose and goals of a system - noting that according to complex adaptive systems theory, a goal-delivering systems is one that has common values and drivers. Users can play a key role during phases of re-build, re-design or during slower pace change. When users are involved in the design of the system, they become owners of the system.**

Question 4: How can an understanding of the Australian healthcare system as a complex adaptive system accommodate or support adoption of person-centred care?

Premise: That complex adaptive systems thinking is compatible with a vision to deliver care that prioritises the consumer experience and values.

Systems thinking approaches

People and Person-centred health care (PPCHC) has been at the heart of recent attempts to improve the quality and responsiveness of the health system. It requires a major shift from established modes of clinical and administrative practice, making individuals, with their complex needs and preferences, the drivers of health care.

Health systems exert a high degree of complexity. It consists of multiple complex systems, comprising a large number of agents are connected along multiple pathways. Within the system, and sub-systems, the effect of any one action or event is rarely proportional to cause. The enabling and delivery of person and patient-centred care, with its focus on customising care to the needs of individuals, inevitably adds even greater complexity to the system. (53)

PPCHC is a not only a desirable goal but necessary for good health care practice. In Australia, adoption of PPCHC will mean moving even deeper into what Berwick describes as a health care system with the simultaneous pursuit of the Triple Aim: improving both the experience of care, the health of populations, and reducing per capita costs of health care. (92). Systems thinking tools such as dynamic simulation models can assist in navigating these conflicting goals.

> *"In the context of health care delivery, a patient-centered approach requires an understanding of the multiple and diverse determinants of health outcomes and patient experience. Modelling these relationships and interdependencies at the system level can provide a comprehensive view of the drivers that improve the quality of the patient visit experience, such as shortened waiting times, quality of information, and access to care. Care pathways can be designed to better reflect patient preferences for certain subgroups, such as risk tolerance for therapies, the avoidance of adverse effects, potential adherence to therapeutic regimens, or demographic characteristics and medical history. In the complex interactions between doctors and patients, simulation modelling may also yield insights into revealed versus stated preferences."*
> *(53)(Marshall et al 2015 . P 8).*

PPCHC and has been a key component within the integrated care frameworks now actively pursued in Australian health policy. This framework is closely related to system thinking and it has been extensively reviewed in the accompanying expert report by the authors on person-centred health care. (93) The perspective of the Australian health care system as a complex system is fully compatible with a person-centred model. However, the goal of PPCHC must be located in a systems analysis. PPCHC needs a complementary strategy to build integration across the care system. A narrower perspective loses sight of the totality of needs and will increase inefficiencies, inequalities, unwarranted variation and waste in the system.

PPCHC requires simultaneous change from the bottom up (e.g. individuals' understanding of their health) and top down (e.g. reallocating resources to enable providers to deliver needs-based care). The key learning is that substantive change towards PPCHC will require systems thinking fit for purpose in the Australian context. These points are developed in more detail in a separate expert commentary by the authors on

Person-centred care. That commentary identified the following facilitators in a system-wide move towards PPCHC:

- Engagement with the person and people, shared management and decisions around health care services
- Strong government and clinical leadership
- The integrated information systems and care pathways
- Inter-sector collaborations
- Focus on patient empowerment

For PPCHC to be achieved in a complex health systems system, specific actions, events and interventions must integrate the level of individual practice (nano, micro) and organisational and whole system levels (meso and macro). Systems thinking will aid in identifying the complexity of factors that influence a person's domains of health, such as environmental and personal factors and the relationships between various components of the health care system.

Again, there is a great potential for widespread adoption of mapping and modelling techniques in the Australian health system to aid health planning and policy to move the system closer to delivering PPCHC. However, there is a need for caution. Even the most comprehensive models require some level of aggregation of preferences, actions and consequences. Decision based on models can be a step closer to PPCHC, but are still not adapted entirely to the individual. Rather models assist decision-makers to become aware of how a system works and apply this knowledge in practice.

The use of modelling also faces barriers to implementation of use that should be taken into account. Simulation modelling and mapping requires specialised skills and adequate data to populate them. Models are also based on series of assumptions that can be subject to challenge and debate. The more sophisticated the model (as is the case for dynamic system modelling), the more difficult it is to explain their logic, which can meet with resistance from some policymakers. The greater the number of domains of interest, the more sophisticated (and resource intensive) the mapping and modelling will need to be.

The Commission may consider the widespread uptake of simulation modelling for health service programs and within the Australian Health System of the Australian Health System. The potential benefits of which would need to be assessed on a localised basis. The SIMULATE Checklist, developed by Marshall's group in 2015 may be one tool that can be used to judge those instances where the use of systems based simulation models would be appropriate.

With adequate models of agents and connections and context, systems thinking can also be applied to determine the relative strengths and weaknesses of interventions aimed to achieve change at any system level.

Key messages for policy

- **PPCHC is a not only a desirable goal but necessary for good health care practice.**
- **The enabling and delivery of person and patient-centred care, with its focus on customising care to the needs of individuals, inevitably adds even greater complexity to the system.**
- **PPCHC requires a major shift from established modes of clinical and administrative practice, making individuals, with their complex needs and preferences, the drivers of health care.**
- **Substantive change towards PPCHC will require systems thinking fit for purpose in the Australian context.**
- **There is a great potential for widespread adoption of mapping and modelling techniques in the Australian health system to aid health planning and policy to move the system closer to delivering PPCHC.**

- **However, there is a need for caution. Even the most comprehensive models require some level of aggregation of preferences, actions and consequences. Decision based on models can be a step closer to PPCHC, but are still not adapted entirely to the individual.**
- **Rather models assist decision-makers to become aware of how a system works and apply this knowledge in practice.**

Complex adaptive systems theory

Moving the Australian health system towards a complex adaptive system that is coherent and goal-delivering, requires a focal point (driver) to guide activities to achieve integration within and across organisational levels of care. The authors of this report are convinced that a person-centred focus is most appropriate for a health system that meets the needs of the Australian community, as:

- individuals experience the same disease in very different ways
- individuals' circumstances surrounding the development of a disease have major implications for their management, and
- not all diseases respond best to biomedical interventions, in many cases social and environmental support results in *better health outcomes* for that person

The authors don't underestimate the challenges in achieving a person-centred health system. Taking a CAS theory approach, the main challenge from the whole of system perspective relates to how to transform the values that sustain the current system. What needs to be facilitated is a system-wide conversation about the general expectations and approaches to healthcare. Policy agencies have a key role to play in this conversation by:

- encouraging local solutions to whole system problems
- giving attention to environmental factors that contribute to health – and ill-health
- acknowledging and leading discussion on what drives action in our health system
- promote multi-stakeholder involvement in health system – and sub-system, reform and design
- promoting key principles (e.g. People, Person and Patient centred care) at all system levels

Key messages for policy

- **There are major challenges to achieving a person-centred health system.**
- **Evidence points to "person-centredness" being the right driver for a complex adaptive health system**
- **Taking a CAS theory approach, the main challenge from the whole of system perspective relates to "how to transform the values that sustain the current system".**
- **System change requires policy leaders to engage all stakeholders in defining the right driver for the health system**

Appendix I: Complexity sciences conceptual framework

In this appendix we quote large sections from key texts that, in our opinion, provide the most concise, yet comprehensive foundations to complex adaptive systems theory.

The philosophy of Complex Adaptive Systems – Paul Cilliers

Excerpt from Cilliers 2013, p. 30 (94). References and footnotes from the original have been removed.

The notion "complexity" has been used in a somewhat general way, as if we know what the word means. According to conventional academic practise it would now be appropriate to provide a definition of "complexity". I will nevertheless resist this convention. There is something inherently reductionist in the process of definition. This process tries to capture the precise meaning of a concept in terms of its essential properties. It would be self-defeating to start an investigation into the nature of complexity by using exactly those methods we are trying to criticise! On the other hand, we cannot leave the notion of "complexity" merely dangling in the air; we have to give it some content. This will be done by making a number of distinctions which will constrain the meaning of the notion without pinning it down in a final way. The characterisation developed in this way is thus not final – in specific contexts there may be more characteristics one could add, and some of those presented here may not always be applicable – but it helps us to make substantial claims about the nature of complexity, claims that may shift our understanding in radical ways.

In the first place one should recognise that complexity is a characteristic of a system. Complex behaviour arises because of the interaction between the components of a system. One can, therefore, not focus on individual components, but on their relationships. The properties of the system emerge as a result of these interactions; they are not contained within individual components.

A second important issue is to recognise that a complex system generates new structure internally. It is not reliant on an external designer. This process is called self-organisation. In reaction to the conditions in the environment, the system has to adjust some of its internal structure. In order to survive, or even flourish, the tempo at which these changes take place is vital (see Cilliers, 2007 for detail in this regard). A comprehensive discussion of self-organisation is beyond the scope of this chapter (see Chapter 6 in Cilliers, 1998 for such a discussion), but some aspects of self-organisation will become clear as we proceed.

An important distinction can be made between "complex" and "complicated" systems. Certain systems may be quite intricate, say something like a jumbo jet. Nevertheless, one can take it apart and put it together again. Even if such a system cannot be understood by a single person, it is understandable in principle.

Complex systems, on the other hand, come to be in the interaction of the components. If one takes it apart, the emergent properties are destroyed. If one wishes to study such systems, examples of which are the brain, living systems, social systems, ecological systems and social-ecological systems, one has to investigate the system as such. It is exactly at this point that reductionist methods fail.

One could argue, however, that emergence is a name for those properties we do not fully understand yet. Then complexity is merely a function of our present understanding of the system, not of the system itself. Thus one could distinguish between epistemological complexity – complexity as a function of our description of the system – and ontological complexity – complexity as an inherent characteristic of the system itself. Perhaps, the argument might go, all complexity is merely epistemological, that finally all complex systems are actually just complicated and that we will eventually be able to understand them perfectly.

If one follows an open research strategy - a strategy which is open to new insights as well as to its own limitations - one cannot dismiss the argument above in any final way. Nevertheless, until such time as the emergent properties of a system are fully understood, it is foolish to treat them as if we understand them already. Given the finitude of human understanding, some aspects of a complex system may always be beyond our grasp. This is no reason to give up on our efforts to understand as clearly as possible. It is the role of scientific enquiry to be as exact as possible. However, there are good reasons why we have to be extremely careful about the reach of the scientific claims we make. In order to examine these reasons in more detail, a more systematic discussion of the nature of complex systems is required. The following characteristics will help us to do this:

1. *Complex systems are open systems.*
2. *They operate under conditions not at equilibrium.*
3. *Complex systems consist of many components. The components themselves are often simple (or can be treated as such).*
4. *The output of components is a function of their inputs. At least some of these functions must be non-linear.*
5. *The state of the system is determined by the values of the inputs and outputs.*
6. *Interactions are defined by actual input-output relationships and these are dynamic (the strength of the interactions change over time).*
7. *Components, on average, interact with many others. There are often multiple routes possible between components, mediated in different ways.*
8. *Many sequences of interaction will provide feedback routes, whether long or short.*
9. *Complex systems display behaviour that results from the interaction between components and not from characteristics inherent to the components themselves. This is sometimes called emergence.*
10. *Asymmetrical structure (temporal, spatial and functional organisation) is developed, maintained and adapted in complex systems through internal dynamic processes. Structure is maintained even though the components themselves are exchanged or renewed.*
11. *Complex systems display behaviour over a divergent range of timescales. This is necessary in order for the system to cope with its environment. It must adapt to changes in the environment quickly, but it can only sustain itself if at least part of the system changes at a slower rate than changes in the environment. This part can be seen as the 'memory' of the system.*
12. *More than one legitimate description of a complex system is possible. Different descriptions will decompose the system in different ways and are not reducible to one another. Different descriptions may also have different degrees of complexity.*

If one considers the implications of these characteristics carefully a number of insights and problems arise:

- *The structure of a complex system enables it to behave in complex ways. If there is too little structure (i.e. many degrees of freedom), the system can behave more randomly, but not more functionally. The mere 'capacity' of the system (i.e. the total amount of degrees of freedom available if the system was not structured in any way) does not serve as a meaningful indicator of the complexity of the system. Complex behaviour is possible when the behaviour of the system is constrained. On the other hand, a fully constrained system has no capacity for complex behaviour either. This claim is not quite the same as saying that complexity exists somewhere on the edge between order and chaos. A wide range of structured systems display complex behaviour.*
- *Since different descriptions of a complex system decompose the system in different ways, the knowledge gained by any description is always relative to the perspective from which the description was made. This does not imply that any description is as good as any other. It is merely the result of the fact that only a limited number of characteristics of the system can be taken into account by any specific description. Although there is no a priori procedure for deciding which description is correct, some descriptions will deliver more interesting results than others.*
- *In describing the macro-behaviour (or emergent behaviour) of the system, not all the micro-features can be taken into account. The description on the macro-level is thus a reduction of complexity, and cannot be an exact description of what the system actually does. Moreover, the emergent properties on the macro-level can influence the micro-activities, a phenomenon sometimes referred to as "top-down causation". Nevertheless, macro-behaviour is not the result of anything else but the micro-activities of the system, keeping in mind that these are not only influenced by their mutual interaction and by top-down effects, but also by the interaction of the system with its environment. When we do science, we usually work with descriptions which operate mainly on a macro-level. These descriptions will always be approximations of some kind.*

These insights have important implications for the knowledge-claims we make when dealing with complex systems. Since we do not have direct access to the complexity itself, our knowledge of such systems is in principle limited. The problematic status of our knowledge of complexity needs to be discussed in a little more detail. Before doing that, some attention will be paid to three problems: identifying the boundaries of complex systems, the role of hierarchical structure and the difficulties involved in modelling complexity.

Tackling the most difficult questions? – David Krakauer

Excerpt from Krakauer 2015. (95)

One quite useful distinction that one can make is between the merely complicated and the complex. So the universe is complicated in many parts; the sun is complicated, but in fact I can represent in a few pages of formula how the sun works. We understand plasma physics; we understand nuclear fusion; we understand star formation.

Now, take an object that's vastly smaller. A virus, Ebola virus. Got a few genes. What do we know about it? Nothing. So how can it be that an object that we'll never get anywhere close to, that's vast, that powers the Earth, that is responsible in some indirect way for the origin of life, is so well understood, but something tiny and inconsequential and relatively new, in terms of Earth years, is totally not understood? And it's because it's complex, not just complicated. And what does that mean?

So one way of thinking about complexity is adaptive, many body systems. The sun is not an adaptive system; the sun doesn't really learn. These do; these are learning systems. And we've never really successfully had a theory for many body learning systems. So just to make that a little clearer, the brain would be an example. There are many neurons interacting adaptively to form a representation, for example, of a visual scene; in economy, there are many individual agents deciding on the price of a good, and so forth; a political system

voting for the next president. All of these systems have individual entities that are heterogeneous and acquire information according to a unique history about the world in which they live. That is not a world that Newton could deal with. There's a very famous quote where he says something like, I have been able to understand the motion of the planets, but I will never understand the madness of men. What Newton was saying is, I don't understand complexity.

So complexity science essentially is the attempt to come up with a mathematical theory of the everyday, of the experiential, of the touchable, of the things that we see, smell and touch, and that's the goal. Over the last 10, 20 years, a series of mathematical frameworks—a little bit like the calculus or graph theory or combinatorics in mathematics that prove so important in physics—have been emerging for us to understand the complex system, network theory, agent-based modeling, scaling theory, the theory of neutral networks, non-equilibrium statistical mechanics, non-linear dynamics. These are new, and relatively, I mean on the order of decades instead of centuries; and so we're at a very exciting time where I think we're starting to build up our inventory of ideas and principles and tools. We're starting to see common principles of organization that span things that appear to be very different—the economy, the brain, and so on. So complexity science ultimately seeks unification—what are the common principles shared—but also provides us with tools for understanding adaptive, many body systems. And intelligence for me is in some sense, the prototypical example of an adaptive, many body system.

A general description of systems (nonlinear systems) – Russ Ackoff

Excerpt from Ackoff 1994 (96)

What's a system? A system is a whole that consists of parts each of which can affect its behaviour or its properties. Each part of the system, when it affects the system, is dependent for its effect on some other part, the parts are interdependent; no part of the system or collection of parts of the system has an independent effect on it. Therefore a system as a whole cannot be divided into independent parts. This has some very important implications that are generally overlooked. First the essential or defining properties of many systems are properties of the whole which none of its part has. The performance of a system depends on how the parts fit, not how they act taken separately.

Nominal Definition – Kevin Dooley

Excerpt from Dooley, 1996, p. 2-3 (97).

The basic elements of a CAS are agents. Agents are semi-autonomous units that seek to maximize their fitness by evolving over time. Agents scan their environment and develop schema. Schema are mental templates that define how reality is interpreted and what are appropriate response for a given stimuli. These schemas are often evolved from smaller, more basic schema. These schemas are rational bounded: they are potentially indeterminate because of incomplete and/or biased information; and they differ across agents. Within an agent, schema exist in multitudes and compete for survival via a selection-enactment-retention process.

When an observation does not match what is expected, an agent can take action in order to adapt the observation to fit an existing schema. An agent can also purposefully alter schema in order to better fit the observation. Schema can change through random or purposeful mutation, and/or combination with other schema. When schema change it generally has the effect of making the agent more robust (it can perform in light of increasing variation or variety), more reliable (it can perform more predictably), or more capable in terms of its requisite variety (in can adapt to a wider range of conditions).

The fitness of the agent is a complex aggregate of many factors, both local and global. Unfit agents are more likely to instigate schema change. Optimization of local fitness allows differentiation and novelty/diversity; global optimization of fitness enhances the CAS coherence as a system and induces long term memory.

Schema define how a given agent interacts with other agents surrounding it. Actions between agents involve the exchange of information and/or resources. These flows may be nonlinear. Information and resources can undergo multiplier effects based on the nature of interconnectedness in the system. Agent tags help identify what other agents are capable of transaction with a given agent; tags also facilitate the formation of aggregates, or meta-agents. Meta-agents help distribute and decentralize functionality, allowing diversity to thrive and specialization to occur. Agents or meta-agents also exist outside the boundaries of the CAS, and schema also determine the rules of interaction concerning how information and resources flow externally.

Structure and dynamics of CAS are interdependent – Fritjof Capra

Fritjof Capra (physicist) (98) uses the *vortex* as the prototypical example to illustrate the structure and dynamics of a CAS. Three aspects are of note:

- for a vortex to form and maintain itself it requires a focal point;
- every level within the vortex has unique dynamics; and
- following disturbances to the structural form of the vortex it will re-establish itself autonomously through self-organisation as long as the focal point is maintained.

These features are of particular importance to understanding health systems and their dynamics.

Appendix II – Cynefin Framework

Kurtz and Snowden (11) developed the Cynefin framework to classify these dynamic patterns according to the cause and effect relationships between agents – they can be tightly coupled, more or less loosely coupled or entirely decoupled (Figure 4).

Tightly coupled cause and effect relationships produce highly predictable outcomes, the simple domain where things are clearly known. Cause and effect relationships which include time delays result in outcomes knowable to experts and define the complicated domain. The complex domain is defined by cause and effect relationships that can only be understood in retrospect, and situations that have no obvious signs of cause and relationship belong to the chaos domain.

Agents in human systems have unique identities and are able to change their behaviours in light of changing circumstances, individually and/or collectively, i.e. they have adaptive capacities. Kurtz and Snowden (11) developed the Cynefin model which defines the characteristics of systems based on the components' relationship as "simple", "complicated", "complex" and "chaotic" and their relationships to each other. The central space of "disorder" signifies those issues that require clarification through collective sense-making. This model highlights that we can approach our understanding about a problem from various perspectives, all of which are providing some insights but none of which is exclusively describing the whole in its entirety. In addition, the Cynefin model allows a visual representation of the transitions between linear (greater concern with content) and non-linear relationships (greater concern with context) between system components, and the related degree of certainty (that which can be taught) and uncertainty (that which needs to be learned) arising from their interactions

Two examples highlight the benefits of using the Cynefin framework in the medical context.

Structure and function in health and disease

Understanding structure and function in health and disease. Cells are well understood, and the detailed structure and function of organs (a collective of cells) is well understood by experts. However, the variability of organ function in health and disease is much less clearly understood as many internal and external factors impact on the organised cellular function of the whole body. In acute disease there may be dissociation of function and structure within and between organs that baffles even the most experienced clinician (See figure below).

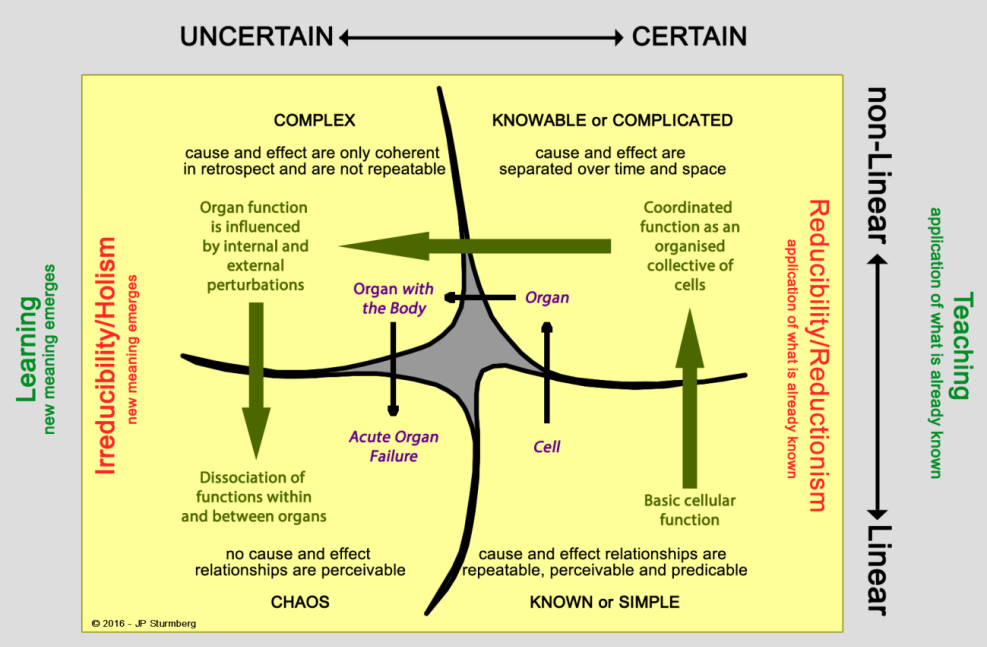


Figure 4: Application of Cynefin Framework health and disease

The culture of safety

Safety reflects the function of the system as a whole. While training and standard procedures are prerequisite for *doing things right*, *doing the right thing* requires collaboration and adaptation in light of changing circumstances. Breakdown of collaboration invariably results in adverse outcomes (See figure below).

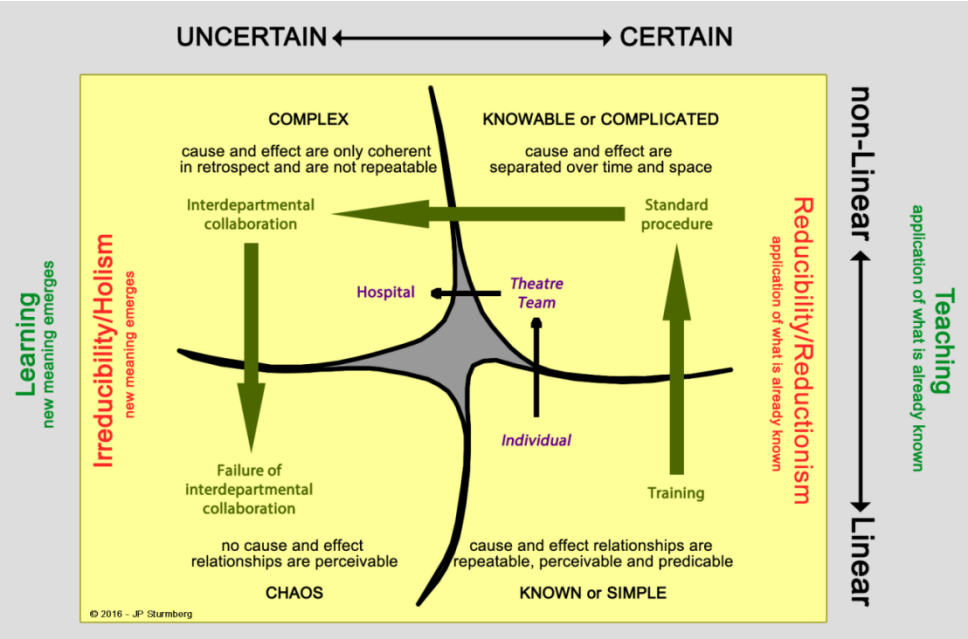


Figure 5: Application of Cynefin Framework to culture of safety

Appendix III – Case study of a complex adaptive (health) system – the NUKA system

Background

Southcentral Foundation is an Alaska Native-owned, nonprofit health care organization serving nearly 65,000 Alaska Native and American Indian people living in Anchorage, Matanuska-Susitna Valley, and 55 rural villages in the Anchorage Service Unit.

Southcentral Foundation NUKA System of Care (https://www.southcentralfoundation.com/nuka/) is a name given to the whole health care system created, managed and owned by Alaska Native people to achieve physical, mental, emotional and spiritual wellness.

Nuka is an Alaska Native word used for strong, giant structures and living things. The relationship-based NUKA-System of Care is comprised of organizational strategies and processes; medical, behavioral, dental and traditional practices; and supporting infrastructure that work together – in relationship – to support wellness. By putting relationships at the forefront of what we do and how we do it, the NUKA-System will continue to develop and improve for future generations.

Vision

A Native Community that enjoys physical, mental, emotional and spiritual wellness.

Key Points

- History
    - For 50 years Alaskan health services were hospital based and run and controlled centrally by a large bureaucracy from Washington
    - Patients were treated as "beneficiaries" – weeks to get an appointment, emergency department became default access point, no continuity of provider
    - Staff were excluded from innovating service organisation and deliver
- Problems
    - Disconnect between care for the mind and care for the body
    - Departments and programmes acted independently
    - Unhappy patients and unhappy staff
    - Poor health statistics
- Change – 1998
    - Southcentral Foundation, owned by Alaska Native people, takes over services for Alaska Native people
    - Community survey to elicit values, priorities and needs [*purpose, goals and values*]
        - Relationship with primary care provider
        - Being treated with courtesy, respect and cultural understanding
        - Access to care when needed
    - Redesign of health services based on the community's values and needs

        - Vision Statement
            - A Native Community that enjoys physical, mental, emotional and spiritual wellness.
        - Mission Statement
            - Working together with the Native Community to achieve wellness through health and related services.
        - 3 "key points" (or simple rules/operating principles)
            - shared responsibility, commitment to quality and family wellness.
    - Continuous improvement
        - listen to people's feedback and understand their needs AND explain the changes being made in response to their feedback AND then communicate the organisation's successes in delivering what the community asked of it

Table 3: CAS features in the NUKA system

What part of the system	Primary care system
Context	Rebuilding a person-centered culturally appropriate primary care system
The agents	NUKA community, Southcentral Foundation, doctors, nurses, allied health professionals, social and community workers
Driver	shared responsibility, commitment to quality and family wellness
CAS-properties	
Non-linearity	• Change to appointment system allows ready access to health service • Change to appointment system allows continuity of care
Open to environment	• Major focus on social factors impacting on health and healthcare delivery
Self-organisation	• Identification of key features for a new health service results in reorganisation of the system's structure and staff behaviours
Emergence	• Health centres transform to meet cultural needs and expectations
Pattern of interaction	• Guided by the three core principles of the organisation - shared responsibility, commitment to quality and family wellness
Adaptation and Evolution	• User feedback guides improvement programmes
Co-evolution	• Health centres become community hubs and meeting centres

Appendix IV: Roles and responsibilities of agents at system levels

Excerpt from Martin and Sturmberg, 2006. (80)

(Note: references that were in the original document have been removed from this excerpt. Please see original for full details).

Macro or policy-level: Policy and financial frameworks need to address population needs as well as the needs of vulnerable groups. The principle of optimal health for all citizens is central to policy innovations in any model of primary health care. Currently prescriptive, "top down", hierarchical and linear policy approaches predominate. In "bottom up" approaches, general practice may advocate for patients and lobby for strategies that provide considered multimodal frameworks in which all stakeholders work together to develop locally appropriate solutions.

Meso or organizational and local-level: Addressing health needs and health related determinants at a regional/local level requires coordinated responses from both health providers and administrators. In order to facilitate the evolution of new, locally relevant service models, it is important to allow key stakeholders to operate in an open rather than heavily prescriptive planning environment. For example, the general practitioner/family physician, thus has a developing organizational and knowledge brokerage role in interdisciplinary and intersectoral care, and in the uptake of new technologies, while at the same time maintaining the core principles of personalized care delivery. This requires the translation of research knowledge, ensuring patients' equity and access to timely health care, and the sharing and coordinating of health care between the wide range of health care and non-health agencies.

Micro or individual-level: Patients and their communities are the centre point around which care is provided and organized. The effectiveness of the roles and responsibilities of general practice rests in the consultation and the personalized interaction of the doctor/provider with an individual. The consultation is the basic "production unit" in medicine – here decisions about resource consumption are negotiated between the doctor and the patient. Yet roles and responsibilities in this area are evolving with care delegation, new patient expectations, electronic information systems and internet medicine. Crucially there is an increasing advocacy and leadership role to keep the patient (not a disease, a cost or a multidisciplinary team) central to the health system and to ensure their core care remains continuous, coordinated, relationship-based and located in primary health care.

Nano or organismic-level: The level of health – subjective as well as objective – reflects the entire impact of the forces influencing human health. Health perception, that is, the subjective experience of health or disease, is the result of the person's interdependence (a term coined by Ban-Yar) with his/her environment. In other words, a patient's experience of healthcare is an outcome reflecting the effectiveness of consultations – nature and nurture, and the workings of the health system at large. However, in the end it is the organism and its embodied experiences of mind, body and emotion that we label "health". This is where health care is directed and has its raison d'être. The judgement of primary health care success is ultimately located at this level. Increasingly this is where the role and responsibility of general practice lies.

Table 4: Agents and their interests in the health system

Level	Agents of Influence	Agents' Interests

macro	• Government Policymakers
	  ○ Health
	  ○ Social services
	  ○ Social Infrastructure
	  ○ Environment
	  ○ Economics and finance
	  ○ others – education, work & employment, housing etc
		• Resource Allocation
		  ○ Determined by perceived priorities
		  ○ Has financial control over health system
		  ○ Balanced Budget

	• Private Enterprise
	  ○ Pharmaceutical industry
	  ○ Device makers
	  ○ Medical associations
	  ○ Health insurance industry
		• Market Share and Profits
		  ○ Getting new drugs developed and accepted on formularies
		  ○ Financial interest of members
		  ○ Growing membership and market share from public health system

	• Citizen Lobby Groups
	  ○ Health User Forum
	  ○ Disease-specific support groups
		• Getting greater resources for their specific interests

	• Non-Government Organisations
	  ○ Research Councils
	  ○
		• Getting greater resources for their specific interests

meso	• Local community infrastructure/environment
	  ○ Work
	  ○ Education
	  ○ Housing
	  ○ Roads
	  ○ Social infrastructure
	  ○ Open spaces
	  ○ Others
		• Dependent on cooperation with other interests
		• Resource constraints
		• Focused on specific tasks
		• Shifting priorities with shifting government agendas

	• Public hospital care
	  ○ Hospital departments
	  ○ Community outreach services
		• Resource constraints
		  ○ Compartmentalised according to organ-system or technology
		  ○ Unstable workforce
		  ○ Staffing shortages
		  ○ High level of bureaucracy
		  ○ Performance based on throughput

	• Private hospital care	• Return on investments
		  ○ Customer focus: doctors and specialists
		  ○ Performance based on maximizing revenue per patient day

micro	• Health service delivery
	• Primary
	  ○ GP-practice team, incl. reception staff, nurses, psychologists,
		• Private enterprise concerns
		  ○ FFS-system of remuneration
		  ○ Competition between practices
		  ○ Resourcing according to income generation potential

	indigenous health workers, others
	• Pathology/Radiology
	• Specialist
	• Community
	  ○ Community nursing
	  ○ Physiotherapy
	  ○ Psychology
	  ○ Other allied health professionals
		○ Over-servicing incentive
		○ Time = money, referral an easy option
		○ Fragmentary care
		○ Limited liaison with other health professional providers
		○ Limited evaluation of health outcomes

micro	• Family, friends and social networks	• Financial constraints • Limited knowledge about patient care and support • Difficulties accessing community support services
nano	• The person	• Concerned about their health experience, does it limit desired levels of activity • Safety of self-management • Financial constraints • Difficulties accessing community support services

Appendix V: Members of Expert Panel

Scholem Glouberman
Trisha Greenhalgh
Tim Holt
Holly J. Lanham
Carmel Martin
Di O'Halloran

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