ISBN number for SETE2020: 978-1-925627-44-2

Managing complex systems and projects

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ABSTRACT

The purpose of the paper is to identify a group of complex systems models and parameters which are relevant to the management of both systems engineering and construction projects. Complex adaptive systems are primarily influenced by emergence, self-organisation and dynamic systems. A group of interviews of many practitioners in the USA, by Heaslip (2014), are recognising in which there are two primary inputs to project management, these being the original planning, which was generated by the project team, and the governance provisions by an enterprise governance committee. However, it is found that adaptivity is required in complex projects and this responsibility needs to be at the enterprise level of programs and/or portfolios. Recognising Ashby's requisite variety, consideration is given of addressing the future proactively by scenario planning. Basic relevant contribution to theory includes examination or a major project centre in China supporting hundreds of projects and the elements of complexity which are encountered. Support for adaptability is provided by understanding of leadership, of double loop learning and a range of other factors. A group of complex systems parameters, developed from complexity theory, an examination of a group of megaprojects and a group of major engineering failures, which neglected to recognise parameters such as mindfulness, preoccupation with failure, normalising deviance and humility, are proposed as among a group of non-functional requirements for systems engineering projects. A general model which applies to both complex construction projects and systems engineering projects, recognising scenario planning, Beer's viable systems model, fractals, megaprojects, double-loop learning, soft-systems methodology, and other factors illustrating the use of these complex system parameters, is proposed.

1. INTODUCTION

The purpose of the paper is to identify a group of complex systems models and parameters which are relevant to the management of systems engineering and construction projects. Some of these models and elements have a relationship to each other, but as basic elements of complex systems, of emergence, dynamic systems and self-organisation, whereas others are simply elements of complex adaptive systems that can be applied to systems engineering and construction projects.

The author's experience is that many systems engineering and construction projects are managed in a reasonably traditional manner and do not recognise the benefits of complex systems.

Complex adaptive systems (CSA) have developed over the past 60 or 70 years, initially with Ross Ashby's statement on requisite variety (1956) and then the major paper by Herbert Simon, for which he received the Nobel Prize in 1972. Further major contributions came from Ilya Prigogine and Murray Gell-Mann, for which both received a Nobel Prize, and further Nobel laureates, including Arrow and Daniel Kahneman, These contributions came from people with a range of backgrounds.

Complexity science is the 'study of the behaviour of large collections of … simple, interacting units, endowed with the potential to evolve with time' (Coveney, 2003, p. 1058). Some aspects of description are clear and direct, including the relationships between the system and its external environment, behaviours of elements of the system which produce system properties, such as birds flocking and fish schooling. Somewhat unpredictable emergence is relevant, such as new behaviours in society.

It is generally considered that the main elements of complex systems are emergence, self-organisation (Heylighen 2013) and dynamic systems (Kaisler and Madey 2009). Elizabeth McMillan (2008), discusses dynamic systems, both how one manages systems which keep changing values and also the benefits of taking a dynamic approach to explore complex issues.

The approach to the issue of Heaslip (2014), in which he provides a set of interviews of practitioners, and then integrates these with elements of theory, needs to be integrated into a discussion. Emergence is discussed in some detail by Lichtenstein (2014), self-organisation by ants, TREES and bees by Trewavas (2014)

The author has also recorded a set of complex systems parameters, which describe behaviours of complex systems, which need to be recognised. These include traditional systems dynamics, initially developed by Sterman (2000) at MIT, also a range of behaviours which address complex issues, such as reference class forecasting, developed by Flyvbjerg (2016), self-organisational criticality recognised by Bak (1996). Complex risks and cascading risks (Helbing 2014), complex behaviour of stakeholders are also included. The author has also examined a number of major engineering failures, and identified that some complex system parameters, such as mindfulness, preoccupation with failure, normalising deviance, and arrogance, are relevant.

2. INTEGRATING THE APPROACHES INTO A STRATEGY AND GUIDANCE FOR MANAGINGMENT OF COMPLEX ADAPTIVE SYSTEMS

A range of complex adaptive system aspects will be discussed in this section.

2.1 What the practitioners said – Heaslip

Richard Heaslip (2014) conducted a series of interviews of practitioners, initially recognising that there are two forms of authority operating on projects, the planning managed by the project manager and team, and the governance systems managed by another group within the project enterprise. However, he then found that the response of these two groups was not adequate to deal with the rapidly changing project environment and this needed to be dealt with at the program level so that adaptation could be emphasised and fully supported.

Heaslip recognised that leadership was crucial and he initially integrated the contribution of Uhl-Bien et al (2007), which recognised that traditional leadership has been in terms of positions with delegations of authority, whereas Uhl-Bien et al (2007) proposes separating operational leadership from leadership of developing staff,. His recognition of the need for adaptation within enterprise based approaches and attitudes, can also include open communications, clear boundaries and a clear set of values (Carapiet & Harris 2007), and Stacey's concept of the Complex Responsive Process of Relating (2001 & 2011), as well as double loop learning (Argyris 2002).

Heaslip's model for the combination of inputs by the project manager and governance system at the project level, and adaptive behaviour at the enterprise level, is shown in his Fig 9.1

Heaslip's Fig 9.3 indicates that most of the adaptive leadership occurs during the project reviews which occur as part of the governance provision. The author's experience is that adaptive leadership is primarily occurring at the enterprise level is endorsed.

The aspects of adaptive leadership of open communications, clear boundaries (for example how you communicate with the Chief Executive concerning your view that basic elements of the enterprise need to change) and clear values, need to be augmented by aspects of styles of leadership (Carapiet & Harris 2007). Detailed statements of values, which include value statements and processes to achieve outcomes, for example the benefits of delegations of the edge (Alberts and Hayes 2003) and more detail on self-organising leadership, such as illustrated by Knowles (2007) in his Fig 4. Double loop learning recognises the difference between single loop, which is correcting the basis of outputs, to fundamentally changing the structure of the organisation to create a system whereby people continually learn by adjusting structures, processes, and attitudes of the organisation.

Getting to the future first, via scenario planning, is discussed in 2.6 and illustrated in Fig 1

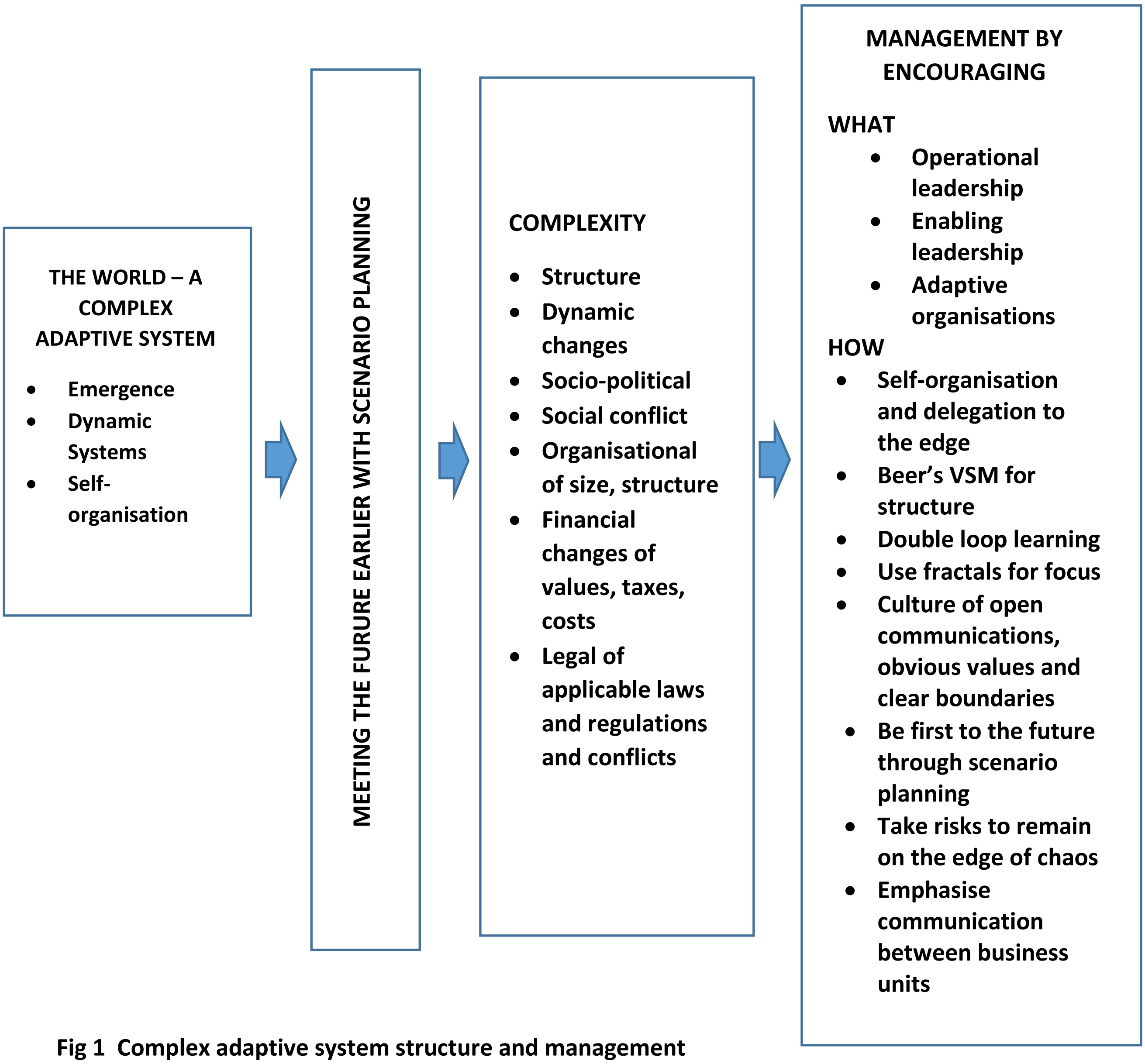

Fig 1 Complex adaptive system structure and management

2.2 Competencies of an adaptive project manager

‘Adaptive leadership is defined as emergent change behaviors under conditions of interaction, interdependence, asymmetrical information, complex network dynamics, and tension. Adaptive leadership manifests in CAS and interactions among agents rather than in individuals, and is recognizable when it has significance and impact’ (Uhl-Bien et al 2007).

Uhl-Bien et al (2007 further points out about complex adaptive systems (CAS), which needs to underpin this paper:

- CAS are a basic unit of analysis in complexity science.
- They are neural-like networks of interacting, interdependent agents who are bonded in a cooperative dynamic by common goal, outlook, need, etc.
- They are changeable structures with multiple, overlapping hierarchies, and like the individuals that comprise them.
- CAS are linked with one another in a dynamic, interactive network.
- CAS emerge naturally in social systems (cf. Homans, 1950; Roy, 1954).
- They are capable of solving problems creatively and are able to learn and adapt quickly (Carley & Hill, 2001; Carley & Lee, 1998; Goodwin, 1994; Levy, 1992).

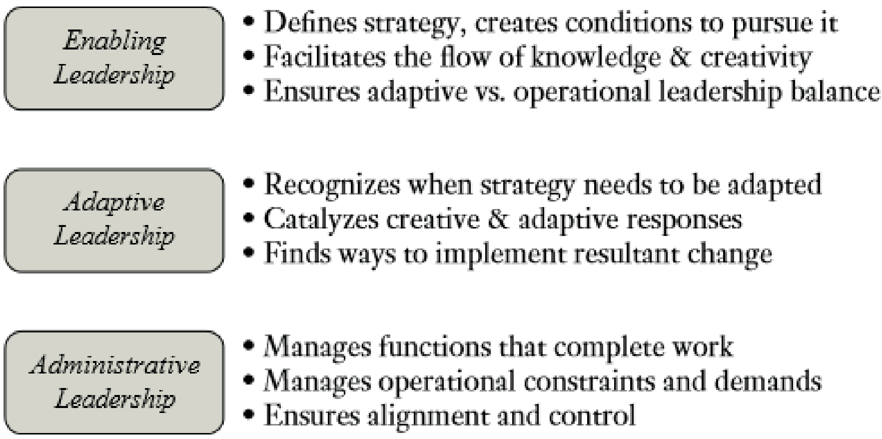

Figure 9.1 Key foci of enabling, adaptive, and administrative leadership.

Adaptive leadership originates in struggles among agents and groups over conflicting needs, ideas, or preferences (Uhl-Bien et al 2007).

Heaslip’s Chapter 13 provides a range of competencies of an adaptive project manager in integrating her views with those of the governance team and the enterprise specialists (p254-255.

The program manager:

a. Actively manages complexity issues with relevant communications between senior executives and team members.
b. Arranges discussions between senior executives and team members on complexity issues.
c. Translates communications from enterprise specialists to project team members by initiating a ‘a bidirectional dialog’. Heaslip recognises that this role involves personal risk for the program manager and uses her ability to ‘to appropriately represent the expert’s view and to engage in dialog with the executive about it’. This requires a high level technical skill and knowledge and the integration of this into project management objectives and processes.
d. Needs to integrate the opinions of the enterprise specialists with her own views.

e. Needs to be capable 'of understanding, representing, and analyzing the perspectives of many program team members, stakeholders, and organizational committees and subcommittees and other stakeholder views in the dynamic exchange of ideas that is critical to the success of complex adaptive systems. This skill requires understanding of complex adaptive systems theory and the interpretation of this to address stakeholder issues in her project'.

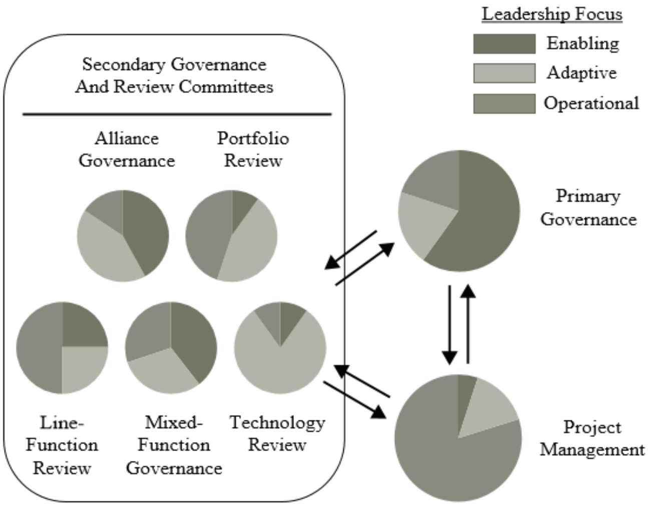

Figure 9.3 Leadership foci of various governance and review committees, as assessed by an individual project manager.

2.3 Emergence

Complex systems recognise emergence as shown in McMillan (2008:63). Emergence occurs because complex systems adapt and transform spontaneously as various agents within the system (people mainly however agents can be informal systems, such as people discussing the organisation over a coffee or a beer) and respond to, and anticipate, change.

> Ants and humans discovered that by working together rather than operating individually they improve their survival chances. For both species obtaining food, defending territories and building and maintaining homes are all more easily achieved by working collectively. Individual ants may not be highly intelligent, but by working together they create a super intelligence. As a group their intelligence is far greater than the sum of their individual parts, or individual ants (McMillan 2008:63-64).

McMillan (2008:201-202) notes that complex adaptive systems:

- consist of large numbers of agents interacting in a non-linear way creating higher and higher levels of complexity.
- have no central controlling mechanism – 'purpose' is at the centre of the model but its function is not controlling. There is no controlling mechanism but the model has its own internal order which arises from the guiding framework created by 'purpose' and 'principles'.
- learn to adapt to changing circumstances – adaptation is shown as an essential ongoing activity.
- actively try to turn events to own advantage – although not shown specifically this is an implied aspect of learning and adaptation.
- constantly revise and change their structures as they learn about the world – this is a feature of learning, specifically double-loop learning.
- anticipate the future: new structures and new forms may emerge as a result of spontaneous learning and adaptation responses to other processes.
- seek to exist on the edge of chaos – this is the overall aim of the model.

• have emergent properties – this is an implicit outcome in the model and use of the different ongoing activities within the overall process.

A skill of the enterprise project manager is to understand self-organisation and to encourage project team members to use self-organisation to solve problems within the project team; 'Emergence involves two interdependent mechanisms: (1) the reformulation of existing elements to produce outcomes that are qualitatively different from the original elements; and (2) self-organization' (Uhl-Bien et al 2007:309).

2.4 Self-organisation

McMillan recognises a new order can be created by self-organisation (p222), Knowles (2007) provides an model recognising the nine key parameters of self-organisation of people in organisations, shown in his figure 4.

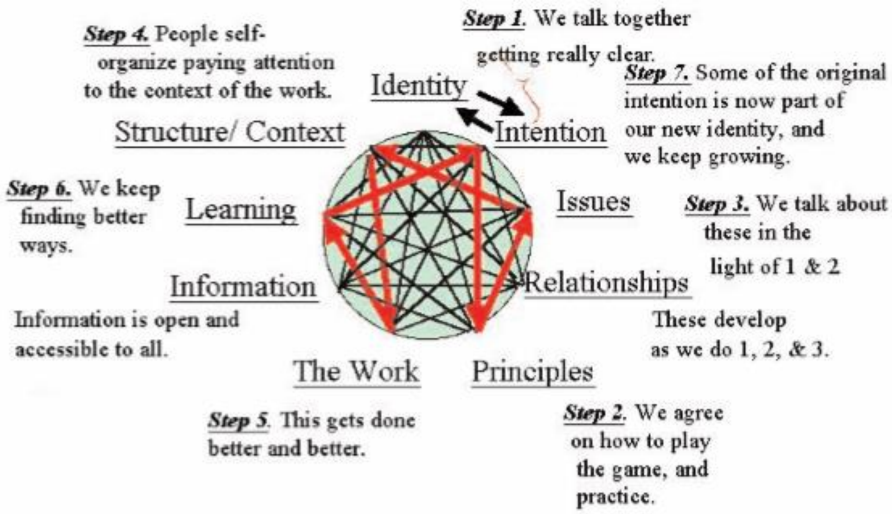

Figure 4 The living pattern and process of how the work gets done

Trewavas (2014) investigated bees, trees and ants and found that they respond to the need for requisite variety in that they: identify when there are inadequate resources to feed the hive, or to sustain the tree and take appropriate action, such as moving the hive or sacrificing leaves or a limb. As not all ants or bees identify this need, a degree of specialisation in roles is required and an ability to judge when resources to sustain the system are not adequate.

2.5 Dynamic systems

Aspects of using dynamic systems as a tool also need to be recognised, as endorsed by McMillan (2008) and Uhl-Bien et al (2007). McMillan recognises that change is constant and looking for linear ways to manage change is not appropriate. However we can benefit by understanding some of the characteristics. Statistical planning predictions are unlikely to be accurate and recognising dynamic systems is more beneficial. For example, exploring dynamic elements of the project system in the early days of project development, while the project is fairly flexible, recognising characteristics of complex systems, such as fractals (Uhl-Bien et al 2007)

McMillan (2008) notes that the 'dynamics of change are created by human activity as feedback amplifies and reverberates across the web of the organization'. This occurs through 'flows of learning and adaptation behaviours, for flows of new information, for flows of ideas, flows of innovative thinking and practice'.

2.6 Scenario planning

Recognising the need for requisite involves recognising change in the system's environment and attempting to control it. In doing so there is value in being proactive through scenario planning.

> Traditional strategic planning typically consists of predicting the future at a single point on a chosen time horizon and mapping the preferred plans to address such a future, scenario planning creates stories about multiple likely potential futures on a given time horizon and maps the preferred plans to address the multiple described potential futures. Each scenario is purposefully different and specifically not a consensus worst-case, average, or best-case forecast; nor is scenario planning a process in probabilistic prediction. Scenario planning focuses on high-impact, uncertain driving forces that affect [the CAS] Uncertainty is the key concept as these forces are mapped onto axes of uncertainty, the poles of which have opposed effects on [the area of interest] – (Emzmann, Beauchamp & Norbash, 2011)

Axes such as "market focus," with their poles, or government support or sponsor response are possible examples.

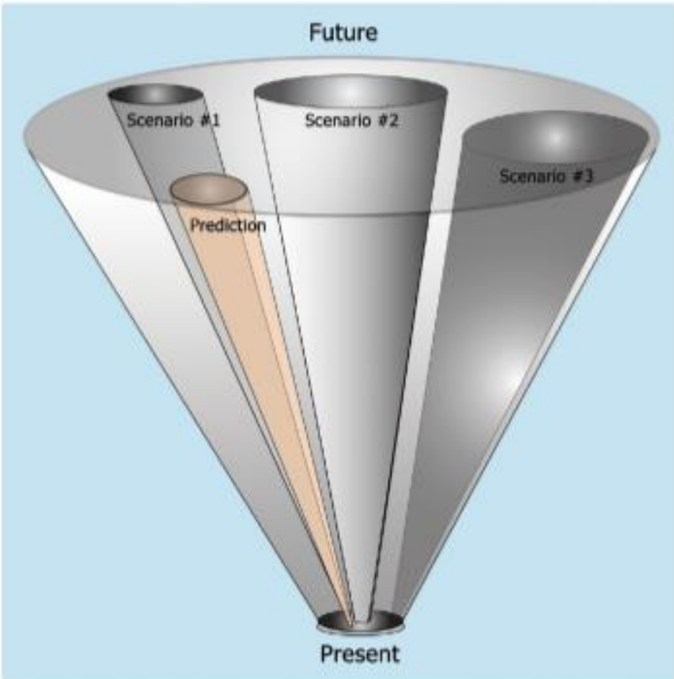

Fig 1. This diagram graphically shows the "cone of possibility" expanding from the "present" to the "future." Within the cone of possibility, scenarios (3 in our case) are selected to cover a large portion of this projected cone, including the more extreme positions at the periphery of the cone. Note that the scenarios are represented by broad cones whereas the prediction cone, by definition, is much narrower. The prediction cone also leaves the majority of the cone of possibility uncovered.

Appropriate scenarios for project management are:

- Monitoring the business environment for changes which will affect the project.
- International competition for project management suppliers.
- Creating competitive advantage for project organisations.

Inclusion of scenario planning may assist in addressing ***we don't know what we don't know***.

2.7 Complexities of project management

Li et al (2015), in examining a government enterprise in Shanghai, which managed over 200 construction projects, found complexity in a range of forms, including:

- Structural (Size, connectivity, architecture).
- Dynamic (short-term or long-term).
- Socio-political (regulation and policy changes).
- Emergence (unanticipated actions).
- Social (conflicts caused by multiple stakeholders; different meanings and perceptions caused by large numbers of project participants; widespread impact on urban environment, transportation, local society, industrial production: complex relationships including formal and informal connections
- Financial: various investment sources, including tax, appropriation, loan, bond and private capital; Inconsistent and changing financial requirements, and difficulty of determining project's cost objects.
- Organisational: large-scale project organizations, complex organizational structures of projects, programs and portfolios; complex organization relationships, blurred interfaces, numerous contracts need to be arranged, and complex contractual relationships;
- Legal: vacancy or immature laws and regulations, mutual conflicts between different laws and regulations, lack of specific regulations or codes to support; agent Construction Model (ACM) delivery; influences from the existing laws and regulations, especially from the new issued laws, such as the property protection by the new construction demolition regulation.
- Technical uncertainty: especially for the underground construction and extreme weather conditions; technology applications influenced by personnel skills and capacities; unproven technologies or controllability of technology induced complexity.
- Time: tight schedule of urbanization, huge pressures from governmental and societal expectations; changes of project objectives and plans caused by enormous factors, such as funds and demolition of existing buildings; large numbers of concurrent tasks.

2.8 Beer’s Viable Systems Methodology

Beer’s viable system methodology is an essential model to recognise in project and systems engineering management with his five levels of governance. Level 1 is based on a fractal of a common governance system for each of the operational areas. Level 2 is the coordination of these and level 3 is the integration, with 3* as the governance provision. Level 4 is the intelligence and level 5 is policy.

2.9 Double loop learning

Argyris (2002) notes that learning occurs when a monitor is corrected for inaccurate behaviour without changing the underlying structure of the monitor (for example a thermostat), however double loop learning occurs when the underlying structure and values of the systems are corrected.

Argyris notes that part of double loop learning is:

- Noticing inconsistencies.
- Asking other staff members for advice on how to address problems.
- Being aware of the workplace culture.

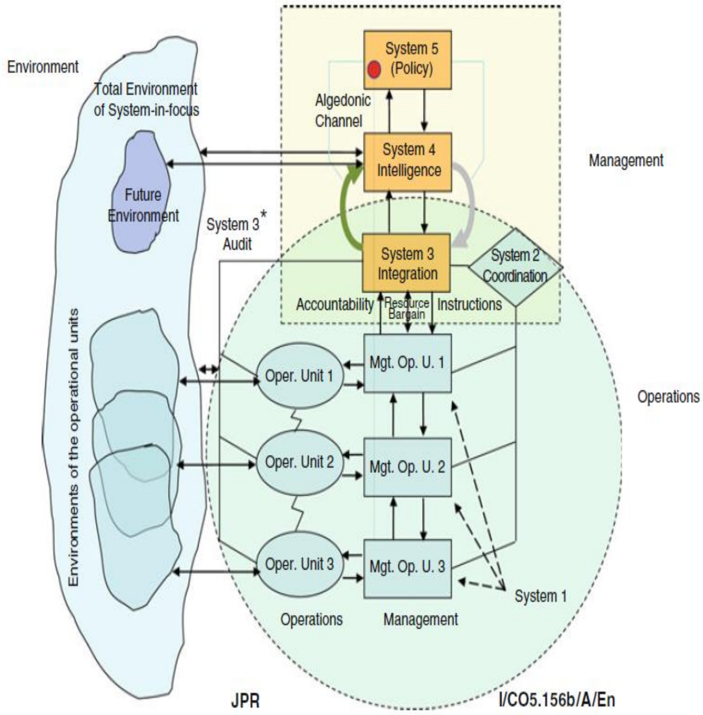

Fig. 1.8 Viable system model (Adapted from Beer 1985)

- Seeking advice from other staff members concerning their view of your failings.
- Not blaming others for your failings.
- Taking responsibility for your actions.
- Being aware of organisational politics.
- Both individual and group reflections on relevant issues.
- In-group discussions, including listening, rather than waiting for the answers you want to hear.
- Engaged new staff with different beliefs to your own.
- Avoiding being an action oriented leader, with inadequate pre-discussion and thought.
- Ensuring effective communications between the various power centres of the organisation, such as project manager, governance committees and the corporate group.
- Attempting to deal with groups who are unaware that they are unaware of a range of issues for effective adaptation.
- Ensuring that self-reinforcing and self-supporting, counter adaptive views, are reduced or eliminated (for example ‘dumbing down’ - the authors addition).

A fundamental behaviour in double loop learning is to counter what Argysis calls organisational defensive routines. These may include routines such as to avoid individuals feeling of embarrassment or threat but at the same time preventing them from discovering the cause of the embarrassment or threat.

Model 1 illustrates genuine learning overprotection.

Examples of dumbing down are provided by Weick & Sutcliffe (2016) and include comments such as:

- Is questioning encouraged at all levels of our organisation?
- Are people encouraged to express different views of what is happening? When they do this, do we label them as trouble-makers?
- Are people shot-down when they report information that could interrupt operations?
- Do people listen carefully to each other? Is it rare that people’s views are dismissed?

- Do we appreciate sceptics around here?
- Do we strive to challenge the status quo?
- Do people show a great deal of respect for each other, no matter what their status or authority?
- Do we develop people's interpersonal skills, regardless of their rank or position?

2.10 Fractals

Fractals are illustrated by McMillan (page 123) as shown in her fig 5.1, which illustrates a repeated pattern of a, b, c, A; a, b, c, B; and, a, b, c, C, in which:

1. A model had to be developed that was applicable to the whole of the company and had to be based on analyses of the behaviour of individuals in the company.
2. The development of knowledge had to be integrated into daily operational activities.

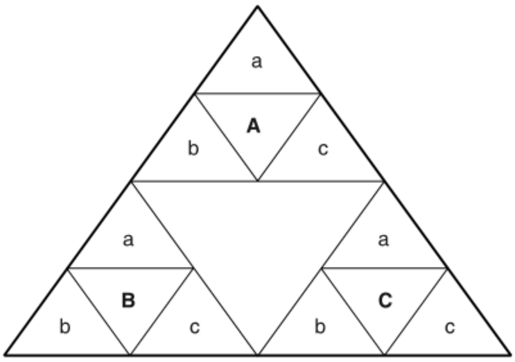

Figure 5.1 Fractal management model at SENCORP.

Source: Adapted from Slocum and Frondorf (2000: 239).

The A realm is dedicated to decision-making, the communication of these decisions and the equal allocation of resources. There are no controlling mechanisms. The B realm is focused on thinking, the development of new ideas, the creation of new knowledge and new possibilities using discussion, analysis and communication. The C realm is concerned with activity and is the 'doing' realm. This is the area where things happen and ideas are implemented. Here the person responsible for the implementation of a new idea or a new option decides how best to make them a reality,

In most organizations employees are given clear cut targets and then monitored for effectiveness and progress by the use of quantitative performance measures. The A realm was given the responsibility of making sure that there was a balance between B and C realms (McMillan 2004: 90).

2.11 Complexities of systems engineering

There are very few research projects which directly examine the role of complexity in systems engineering. Gilbert and Yearworth (2016) generally supports the integration of reductionist techniques and complexity techniques, such as complexity leadership by Uhl-Bien et al (2007), which is supportive of aspects of Heaslip's (2014) approach.

2.12 Complex system parameters lacking in engineering failures

An examination of a number of engineering failures including two NASA space missions, the Fukushima Daiichi nuclear disaster, and the BP Deepwater oil spill in the Mexican Gulf, indicated that a number of complex systems parameters were not observed including:

- Normalisation of deviance on the two NASA missions.

- Preoccupation with failure on the BP Deepwater oil well and arrogance or lack of humility, the Fukushima Daiichi nuclear disaster.

2.13 Examination of megaprojects

A megaproject is to a project what a stress test is to someone with questionable heart condition, in that megaprojects identify the weaknesses of many normal projects. The most comprehensive study of megaprojects was conducted by Dimitriou et al (2013). The study found:

a. It is better to focus on mega transport infrastructure as a combination of social and technical project, rather than purely technical outcomes;
b. High uncertainty of Information.
c. Very unclear boundaries.
d. Missunderstanding of changed investment objectives over time.
e. Difficult to align short and long term objectives.
f. Inadequate planning and appraisal techniques.
g. A dramatic change of mind has occurred concerning the way megaprojects are positioned, framed, planned and judged.
h. Need for polic-led multi-criteria analysis framework (PLMCA).
i. Concern over how well risks and uncertainties and complex decision-making are handled.
j. How the megaproject is framed, planned, planned, positioned, and ultimately judged.
k. When megaprojects are considered as closed systems during the early part of the planning they currently are planned: treating them as closed systems makes them vulnerable to the need for strategic change.
l. The project should respond to any change in context, although such changes can be very costly.
m. Transport planning was conducted without concern for other land use policies such as ecology and farming (Perth to Mandurah rail in Australia).
n. Inadequacies in the original vision or objectives is common.
o. Narrow project objectives versus broader social objectives.
p. Judging of the project revealing a failure to meet original objectives provides a disservice to investors and civil society; when the external environment of project changes, the project may need to change with it.
q. Cost benefit analysis is inadequate to judge megaprojects.

2.14 Saynisch and second order cybernetics

Manfred Saynisch (2010 a & b) proposed what he called second order cybernetics, which was primarily concerned with the need for planners and designers to make a greater effort in supporting project deliverers. Many planners and designers are working on at least two projects at the one time, and the planners are unable to build adequate relationships with the deliverers on the first project, particularly during the on-site execution, because they are too busy coping with being behind in planning the second project.

2.15 Complex systems parameters as non-functional requirements

There are many other complex system parameters, including a group which could be addressed as non-functional requirements. The systems engineer needs to decide whether they are relevant for the particular project:

a. Assessing requisite variety (Boisot & McKelvey 2011).
b. Recognising complex versus complicated (Kurtz& Snowden 2007).
c. Recognition of dynamic systems (Kaisler & Madey 2008).
d. Recognising self-organisation (Knowles 2007).
e. Recognising emergence (Lichtenstein 2014).
f. Creating governance through Beers viable systems model (Hoverstadt 2008).

g. Developing Mindfulness (Weick & Sutcliffe 2016).
h. Preoccupation with failure (Weick & Sutcliffe 2016),
i. Avoiding normalising deviance (Weick & Sutcliffe 2016).
j. Avoiding arrogance or practis he will all ing humility (Omoto 2013);
k. Use of stage-gate: risk versus proposed benefits (Cooper 1986).
l. Incremental Commitment Spiral Model (Boehm et al 2014).
m. Recognising we don't we don't know what we don't know (Taleb 2007).
n. Responding to uncertainty when planning (De Meyer et al 2006).
o. Use of 'V' model to verify and valida te (Forsberg & Mooz 1999).
p. Recognition of complexity in the supply chain (Spiegler et al (2001).
q. Cascading risk (Helbing 2013).
r. Systemic risk (Helbing 2013).
s. Root cause analysis (iSix Sigma).
t. Self-organised criticality (Bak, Tang & Wiesenfeld 1988).
u. Use of fractals (Hoverstadt 2008).
v. Complex Responsive Process of Relating (Stacey 2001 & 2012).
w. System dynamics to understand feedbacks (Sterman 2000).
x. Soft System Methodology (Checkland & Holwell 1998).

2.16 Soft Systems Methodology

SSM, introduced by Checkland (Checkland Holwell 1998), is a useful approach when the objective of the project is not clear. Examples especially include the problems in an organisation. Hodge (2010) combined SSM with Systems Engineering rigor to address defence and health management..

2.17 Complex adaptive behaviour

Adaptation is putting learning put into practice. Without the ability to learn and adapt a complex adaptive system would fail to thrive and survive

The attributes of complex adaptive systems are encapsulated in Table 1 of the author which is developed from MacMillan 2008:201).

Issues for enterprise or program adaptability		**How an enterprise or program would respond**
1	Learning and adaptation: they actively try to turn events to their own advantage	Jack Welch, as chief executive of General Electric, emphasised acquisition of new enterprises in order to gain their ideas and techniques; he also emphasised communication between the old and new, which were kept separate so that one did not limit the other; however the various business units were encouraged to give regular seminars to members of other business units, so the new ideas could be stimulated (author's illustration).
2	They constantly revise and change their structures as they learn	Organisational structures are not fixed but are open for discussion and possible revision,
3	There is no central controlling mechanism	Operational or administrative leadership does exist however principles of equality of people and open communications are emphasised: staff are encouraged to share experiences and report methods of success and failure for common understanding and use.

4	Double loop learning applies	Double loop learning provides a group of processes which seek to provide deeper understanding, such as the Toyota practice of asking why five times.
6	They seek to exist on the edge of chaos	This means being willing to take risks to explore the environment.
7	They have emergent properties	Use of higher capabilities to take on larger and different projects

While commercial enterprises can be flexible, if they choose, this may be more difficult for systems engineering projects in which governments play a major role. Although the role is one of sponsor, there could be restrictions on flexibility.

3 RELENANCE TO SYSTEMS ENGINEERINH

Most of the paper addresses potential benefits to systems engineering projects. A distinctive issue relevance to systems engineers is whether complex systems parameters can be used as non-functional requirements in systems engineering projects, which is addressed in 2.15.

4 RELEVANCE TO PROJECT MANAGEMENT

In recognising the construction project management and systems engineering are quite different types of projects and, in my view, both can benefit from the other. Construction project management can learn from the benefits of using requirements and systems engineering can benefit from the recognition of complex systems parameters as requirements, with various requirements being applicable to the different phases of an engineering project. The consideration of complex systems parameters as possible non-functional requirements in a systems engineering project broadens the scope of the understanding and management to address complex systems much more thoroughly than is normal in systems engineering projects.

5 CONCLUSIONS

The paper includes an extensive study of published research on the application of complex adaptive systems to project management and systems engineering. Benefits that both construction projects and systems engineering projects can occur through this paper, including understanding the multi-aspects of project complexity; the separate recognition of three key aspects of leadership, of operational leadership from inspirational or enabling leadership; and inclusion of adaptive functions within the enterprise; other aspects include recognition of the changing external environment of the project, being proactive by attempting to understand the future by scenario planning; recognising emergence, self-organisation and dynamic systems; use of Beer's viable systems model; using double loop learning and fractals, to assist management; benefiting from a study of megaprojects; understanding second-order cybernetics of Saynisch; considering whether to use complex systems parameters as potential non-functional requirements on systems engineering projects.

A number of areas have not been addressed however, because of the limitations of the size of this paper, aspects such as Keating and Katina's unpublished paper on Complex System Governance: Concept, Utility, and Challenges, which recognises system pathologies, or aspects of systems that are internally dysfunctional, are not discussed.

Much further work is required on the themes introduced in the paper, and the next phase of the author's activities are to test the concepts on both the systems engineering and construction projects. Cooperation would be appreciated from members of SESA in offering their anonymous projects for benchmarking. The author is willing to report back on how individual projects stand against the group.

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