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Engineering asset procurement: A complex adaptive system perspective

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Introduction

The Australian Procurement and Construction Council (APCC) (2001) noted that Australian government assets, such as buildings, roads, rail and utilities, are valued at around $371billion and approximately $18 billion is spent annually by state, territory and commonwealth governments on acquiring and maintaining these assets. Ferguson (2007) estimates that over $200 billion will be spent on engineering assets such as transport (roads and rail), ports, utilities (water and electricity) and broadband in the next few years in Australia. Such engineering assets are highly complex arrangements which comprise social and technical systems, are capital intensive, and typically last for significant lengths of time (Herder and Verwater-Lukszo 2006). Indeed it is considered that the optimal functioning of engineering assets such as “transportation, energy, information and communication, and water is vital for the economy and society” (Herder and Verwater-Lukszo 2006, 119). Engineering assets are thus significant in both economic and social terms (APCC 2001).

Recognising the importance of engineering assets to society, many jurisdictions in Australia have developed policies on the strategic management of engineering assets (e.g. Queensland Treasury 2003, Western Australia Department of Treasury and Finance 2005) particularly in order to guide the procurement of assets, asset management and maintenance, which is now typically achieved through private firms. The APCC (2001) has argued that the effective and efficient management of these assets is in the best interest of government, business and society (APCC 2001). As an emerging field of endeavour, engineering asset management seeks to optimise the performance of these engineering assets – particularly the whole-of-life management of risks and expenditures for the purpose of achieving organisational goals (British Standards 2003). Given the relative newness of the field, much research is still needed in order to identify the optimal ways of procuring engineering asset management and maintenance from the private sector by government (Lædre, Austeng, Haugen and Kaklegg 2006).

Procuring engineering asset management and maintenance is a critical arena in which to conduct research due to the size of expenditure involved in acquiring and maintaining these assets (APCC 2001), the typical longevity of the assets, and the significant risk posed to society if these assets were to fail (Herder and Verwater-Lukso 2006). This paper argues that a richer understanding of the procurement of engineering asset management and maintenance services can be achieved by using perspectives from complex adaptive systems theory. The following sections outline the administrative challenges faced by governments as they seek to arrange for the management and maintenance of these assets, as these arrangements are of central interest to this research project. Firstly, the complex public policy issues which have arisen due to new systems of government in western democracies will be outlined, together with drawing out the implications of these arrangements for engineering asset management. Theoretical perspectives which have been deployed to explore this complexity will then be surveyed, and the utility of complex adaptive systems (CAS) theory to investigate the procurement of engineering asset management will be advanced.

Overview of public policy issues relevant to engineering asset management

The management of government services, such as engineering asset management, was historically conducted by public agencies with in-house staff, occasionally supplemented by external consultants, with ongoing maintenance undertaken for the most part by in-house workforces (Hood 1991). In the early 1990’s significant changes were introduced into western democracies under the rubric of New Public Management (NPM) (Hood 1991). One of the main changes which occurred under NPM was that those tasks which had been conducted previously in-house were contracted-out to the private sector (Domberger 1994). ‘Contracting-out’, as it came to be known, fundamentally changed the nature of service delivery for government agencies (Verspaandonk, 2001), as government moved from delivering services directly, to contracting with the private sector for the delivery of these services.

The introduction of NPM greatly increased the complexity of public services, as it required the development of new sets of relationships between government and the private sector for the delivery of specific services (Rhodes and MacKechnie 2003). Under NPM Government ceased to provide many services directly to the public and instead engaged the services of private firms to deliver, manage and maintain these assets and services on behalf of government (Rhodes 1997). Osborne and Gaebler (1992) note that these new arrangements necessitated a shift in thinking within government away from 'rowing' (or doing the work) to 'steering' (which involved managing and guiding others who work on behalf of government). As a consequence of these changes, governments of all persuasions are still attempting to find the optimal set of arrangements for planning, tendering, contracting and managing the services of numerous private firms (Rhodes 1997), including those who have been contracted to provide the delivery and maintenance of engineering assets (Lædre, et al. 2006). The process of sourcing goods and services by third parties is typically referred to by government as 'procurement'. As outlined by the APCC (2003, 2):

> Procurement takes many forms and encompasses the acquisition of consumables (goods); real property; capital equipment such as computers; built assets such as hospitals, schools, roads and major facilities; and services such as office accommodation, cleaning and security.

The interest of this paper is the procurement of engineering assets, which due to their size, complexity, longevity and potential impact on society if mismanaged, involves a different set of arrangements when compared to procuring smaller disposable items – such as office supplies.

Procurement of engineering assets is in essence a series of decisions about the delivery system, contract model and compensation format for the management and maintenance of a given asset (Lædre et al. 2006). Numerous delivery systems exist in public policy documents which delineate the overarching relationship between the contractor and government, such as managing contractor, alliance contract, or period contract (New South Wales Government 2005). A variety of contract systems exist which establish the range of services being procured from the private sector for a particular asset, such as construct only; design and construct; or design, construct and maintain (New South Wales Government 2005). Numerous funding options also exist. Having determined the need for the asset, a department typically then justifies the need of the asset in order to meet service obligations to society, and includes such plans in forward budget estimates (e.g. Queensland Treasury 2003). The funding for the asset thus becomes part of intra-governmental negotiations over budgetary spending. The actual funding source for a specific asset can be derived from a range of government and private sources (New South Wales Government 2005), as well as from a number of levels of government (Furneaux and Brown 2007b). Thus there are several pathways available for the procurement of engineering assets – including multiple forms of contractual relationships and compensation formats possible in the delivery of infrastructure procurement, with no single best method apparent (Lædre, et al. 2006). Such issues are important as they relate to the efficiency and effectiveness of contractual and financial mechanisms in achieving outcomes for government. Limited literature exists on the appropriate types of procurement arrangements for particular classes or types of asset, and mechanisms which are appropriate for specific situations, which this research seeks to address. As will be outlined below, CAS theory has been advocated as providing a useful framework for the examination of these complex sets of arrangements (Bovaird 2006).

The importance of ensuring engineering assets achieve their intended outcomes in an effective and efficient manner, has meant that asset management practitioner literature has tended to focus on the economic and technical decision making processes which are required for the effective whole-of-life management of these assets (e.g. *INGENIUM* 2002), although attention to the whole of life aspects of these large assets – especially the disposal of these assets – is only recently being addressed (e.g. APCC 2007) . Engineering assets deliver critical services to the wider community, such as the generation of electricity, provision of water, and national defence (Herder and Verwater-Lukszo 2006), and the failure, neglect or sabotage of these engineering assets could result in significant adverse outcomes for society as a whole (Hellström 2007; Godau 1999).

McIntyre and Pradhan (2003) and Goadau (1999) both argue that engineering systems such as energy generation have for too long been considered as purely technological systems, and argue that engineering assets include social, political, economic, and environmental factors. Herder and Verwater-Lukszo (2006), argue for example, that engineering assets are not just pieces of technology, but are really socio-technical systems – consisting of both a social and a technical element – and note that the organisational and social context of engineering asset operations is seldom investigated in research to date. This research project explicitly addresses this gap in the literature by focusing on the range of organisations involved in making decisions concerning engineering assets as these form key stakeholders who should be consulted when making decisions concerning critical pieces of infrastructure (Mitchell, Agle and Wood 1997). As Bridgman and Davis (2004) suggest, public policy arenas “can be a chaotic place in which ideas must find a path between the intentions of politicians, the interests of various government institutions, the interpretation of bureaucrats and the intervention of pressure groups, media and citizens”. Research into engineering assets therefore needs to look beyond the economic and technical aspects of procurement to the wider social, political and environmental context in which the asset is situated. As CAS theory explicitly looks both at the behaviour of agents within a system, and how the external environment of the system affects agents within the system, it would appear to be a suitable framework for addressing the gap identified here.

In summary, engineering asset procurement is concerned with the planning, delivery and maintenance of large assets which involves significant expenditure, and is integral to the functioning of modern industrial societies (Herder and Verwater-Lukso 2006). Current practices have emerged out of a raft of major changes in the public sector which meant that services once provided by government on behalf of society were contracted out to the private sector to deliver on behalf of government (Hood 1991). Procurement is in essence a series of decisions about an engineering asset which should consider technical, economic, political and social factors (McIntyre and Pradhan 2003). Many governments are still searching for the most appropriate way to procure engineering assets and provide an optimal system of management and maintenance (Lædre, et al. 2006), as well as how to govern the ongoing relationships between government and private industry (Rhodes 1997, 48) which are required for the effective delivery and maintenance of these assets. As Jensen and Stonecash (2004, 22) note “Despite its importance as a public policy issue and the amount of research devoted to it, the determinants of successful public sector outsourcing are still largely unknown”. This paper will address this gap in the literature by examining the procurement of engineering asset management and maintenance by government from private firms.

Potential theoretical frameworks for exploring engineering asset procurement

Approaches prevalent in the academic literature relevant to the examination of procurement issues in the public sector are principal-agent theory (Quiggin 1986) and network governance (Keast, Brown and Mandell 2007). More recently, however CAS theory has been mooted as theory that can extend network perspectives of government services (Klijn and Teisman 2007). These are discussed further below.

Principal-agent theory has been a dominant theory in the analysis of government engagement with construction and infrastructure industries. Much of the principal-agent theory literature has focussed on the relationship between the owners and managers of firms – particularly the contractual relationship which is used to reduce risk, and to control opportunistic behaviour, although it has also been applied to relationships between organisations (Eisenhardt 1989). As government is a purchaser of buildings, construction and design firms are seen as the agents of government, who is typically perceived as the principal (Quiggin 1996). Agency theory postulates that people are self-interested at the personal level, and therefore have conflicts of interest in some cooperative endeavours unless these relationships are mediated by arm’s length third party transactions (Jensen 1994). Hence this theory has tended to focus on the specification of details in contracts in order to prevent opportunistic behaviour by firms contracted to provide services to government.

According to Eisenhardt (1989) principal-agent theory only represents a partial and adversarial view of the world, and ignores a great deal of complexity in society, and in the business environment. Part of the complexity is that government can have multiple roles in construction projects such as “assessor of infrastructure needs, project manager, facilitator, performance sector, network planner, concession granter, inspector, contract manager, protector of the environment, and representative of the public interest” (Demirag 2004: 23). Increasingly funds for major projects are drawn from multiple spheres of government, which means that contractors have to meet the rules and regulations of two tiers of governments in order to be eligible to tender for contracts (Brown, Furneaux, Janssen and Allan 2008). Further complexity emerges as multiple departments may become involved in the planning and delivery stages of a project either directly (Furneaux, Brown, McConville, McFallan, London and Burgess 2006a), or indirectly as multiple outcomes are achieved from the procurement process, such as training, regional development and even art delivered as a percentage of the construction project (Austen, Seymour, Brown, Furneaux and McCabe 2007) or occupational health and safety (Brown et al. 2008). Simple notions of principal and agent do not allow for the sheer number and diversity of roles that government can play in individual engineering asset management projects. Eisner, Worsham, and Ringquist (1996) argue that agency theory cannot be applied to complex modern bureaucracies as there are simultaneously multiple agents and multiple principals engaged in the policy making process. In their review of engineering asset management and maintenance Herder and Verwater-Lukszo (2006, 119) argue that “new and more intelligent methods are needed … that are able to handle multi-actor, multi-level, multi-objective and dynamic complexity of infrastructural operation”.

Principal-agent theory has been held to provide significant explanatory power for exploring government contracting, particularly in circumstances which involve fairly straight-forward, and easily measured arrangements between government and contracted firms (Jensen and Stonecash 2004). Given the difficulty for principal-agent theory in dealing with a multiplicity of parties involved in modern procurement arrangements (Eisner, Worsham and Ringquist 1996) such as that which exists with engineering asset management (Herder and Verwater-Lukso 2006), alternative theories are needed which can advance ways of understanding the interactions between the actors. One such theory which has gained considerable attention in recent years is that of ‘network governance’.

Considerable work has been undertaken in recent years to explore the new area of ‘network governance’ (e.g. Keast, Brown and Mandell 2007). Network governance is interested in the networks of agents which are held to exist across most areas of government activity, including the procurement of the management and maintenance of engineering assets (Osborn and Hegedoorn 1997). While NPM introduced delivery by the market of services for government, this did not mean that hierarchy disappeared, as firms were still accountable to government and government was accountable to society. Instead, in addition to hierarchy and market forms of organising the economy, NPM resulted in networks of relationships between suppliers and government developing (Keast, Mandell, and Brown 2006). Consequently hierarchy, market and network forms of economic relationships co-existed in western economies (Rhodes 1997, 48), which resulted in increased complexity due to overlapping of multiple policy domains (Keast, Mandell, and Brown 2006).

While the notion of networks, markets and hierarchies as modes of governance is not new, Rhodes (1997) argues that it is the mix of these arrangements in public service contexts which matters. Recent work has focused on the optimal mix of modes of governance in order to deliver services and products (Provan and Kenis 2007), and the importance of different types of networks (cooperation, coordination, collaboration) for different situations (Keast, Brown and Mandell 2007). Network governance research has begun to advance understandings of how to influence network structure, interaction and outcomes (Klijn and Koppenjan 2006; Provan and Kenis 2007), and the extent to which these networks can be governed (Kooiman 1999). While principal-agent theory is held to not cope with the multiple agents prevalent in the procurement of services by government, Keast, Mandell, and Brown (2006) argue that network governance is able to accommodate multiple agents and objectives prevalent in modern service delivery arrangements. Despite its power and capability of demonstrating interactions between various agents in networked arrangements, Smith and Stacey (1997) argue, however, that such approaches can overlook an important factor – the mixed governance modes of network, hierarchy and market in specific situations will not remain stable but will adapt and evolve and tensions between mixed governance modes will generate new forms of organisation. Klijn and Teisman (2007) agree, also noting that both the governance system and its environment are constantly changing, and that complexity theory helps to explain the way that agents, systems and environments interact and produce change. It is this area of evolution, emergence and adaptation which CAS theory is held to provide a powerful alternative perspective to network governance (White 2001). Pierce (2000), Blackman (2001), and Chapman (2002) have likewise called for CAS research into public policy issues, arguing that this perspective provides a highly useful alternative perspective to other theoretical approaches.

Network governance literature explores alternative modes of governing the sets of relationships involved in the delivery of services to the network, thereby influencing the outcome of the network (Klijn and Koppenjan 2006). Proponents of CAS agree with network theorists that hierarchical approaches to management of complex delivery systems are generally not successful (Rhodes and MacKechnie 2003). Part of the reason for this, according to CAS theory, is that order emerges from the system itself, and that order cannot be imposed externally, as the system will always find ways of adapting to such external controls and minimising their influence (Holland 1998). Thus while a system and a network may appear similar, the means for creating order is perceived differently.

Other authors researching in the area of engineering asset management argue that it is imperative to examine engineering assets from a CAS perspective due to the inter-related nature of the systems, and their importance to modern societies (Rinaldi, Peerenboom, and Kelly 2001). Price and Akhlaghi (1999) and Herder and Verwater-Lukszo (2006) have also argued that engineering asset management needs to be examined from a CAS perspective in order to address the demands of multiple stakeholders. This is achieved by examining the range of agents involved in the system. Godau (1999) argues that traditional approaches to managing engineering assets do not address the conflicting needs of technical, economic, managerial, environmental, political and social agents, and argues that a CAS perspective is needed to take into consideration all of these agendas. An improved understanding of the dynamics of these systems is likely to lead to a better understanding of how to manage the problems encountered within these systems (Smith and Stacey 1997).

Despite all of these calls, Richardson (2006) suggests that CAS as a theory has only newly been applied to real world public policy problems. Klijn and Teisman (2007) agree arguing that there have been relatively few applications of CAS theory to public policy problems. These perspectives are summarised by Parsons:

> The application of complex adaptive systems to social systems is fairly recent and … appears to hold promise for helping us to work within the complexity of today's world (Parsons 2007, 407).

Published reports using CAS as a theoretical approach have been found in a variety of public policy areas including: community involvement (Midgley and Richardson 2007), drug trade (Coyle and Alexander 1997), federalism (Coghill 2004), health care and public health (Bar-Yam 2006; Vennix and Gubbels 1992; White 2000), international development agencies (Smith and Stacey 1997), occupational health and safety (Koppenjan 2001), security services (Meek de Ladurantey and Newell 2007), sustainable development (Daneke 2001; Moxnes 2000) and tobacco excise (Cavana and Clifford 2006). Each of these studies have begun to deploy CAS theory as a framework for examining specific public policy problems. CAS theories have also been applied to marketing (Markose 2005; Wollin and Perry 2004) and economics (Robson 2005). Thus while CAS theory is relatively new to public policy research (Klijn and Teisman 2007) numerous authors are now beginning to apply this theoretical framework to explore a variety of public policy issues. Such calls are not restricted to investigation of general policy matters, but have also emerged specifically in the area of government procurement.

While CAS theory has been held to provide a very useful framework for evaluating the appropriateness of policy initiatives in general (Sanderson 2000), some researchers have also used CAS theory to explore public procurement. One study in the United Kingdom focuses on the various forms of market relationships possible in procurement of government services (Bovaird 2006). Bovaird (2006) argues that CAS theory is a useful theoretical perspective to understand procurement as it provides a framework for examining multiple agents, their relationships, the rules they utilised to make decisions and how these decisions can affect the system overall. Hitchins (2003) also argues that CAS theory is useful in understanding how government procurement arrangements can affect the market, and in turn are affected by the market. Klijn and Teisman (2007) in their exploration of CAS theory use a case study of the procurement of rail management and maintenance services in the United Kingdom. They found the theory useful in identifying the key agents in the system (government and private) and the impact of decisions made by these key agents on the capability of the system (rail) being managed.

In summary, engineering asset management is a significant area of research, as engineering assets involve considerable expenditure by government, and are of critical importance for the effective functioning of modern societies. Such arrangements involve complex sets of decisions concerning funding, contracting, and relationships, (Lædre, et al. 2006) and involve the management of multi-agents and multi-objectives (Herder and Verwater-Lukszo (2006, 119). Numerous authors (Rinaldi, Peerenboom, and Kelly 2001; Price and Akhlaghi 1999; Herder and Verwater-Lukszo 2006; Godau 1999) have argued that engineering assets should be investigated from a complex adaptive perspective. Bovaird (2006) has specifically argued that CAS theory provides a very useful perspective for the examination of government procurement.

Engineering asset procurement is an important area which appears to have not been studied extensively from a CAS perspective to date. This research seeks to expand current literature on the procurement of engineering asset management, by using a CAS perspective, which numerous authors argue is important (Smith and Stacey 1997) and will result in improved understanding and therefore improved management of engineering assets.

Area and topic

This paper will develop and validate a framework for analysing engineering asset procurement from a CAS perspective, which takes into consideration both conceptually and methodologically the complexity associated with the procurement of engineering assets. In short it seeks to develop a richer understanding of engineering asset procurement using CAS theory as a theoretical framework. A better understanding of the dynamics of such a system should in turn result in better management, maintenance and long-term decision making for asset management.

The topic is thus situated in the broad area of public policy. However, a CAS perspective will be utilised to examine a public policy issue: engineering asset procurement.

Literature Review

This section provides an overview of CAS theory, and how this theory provides a useful conceptual framework for examining public procurement of engineering asset management services. Having initially explored CAS, together with some challenges involved with the deployment and operationalisation of the theory in management contexts, specific research questions, problem specification and significance of the study are detailed.

Complexity and Complex Adaptive Systems (CAS)

Complexity is concerned with phenomena which cannot be easily explained by positivistic scientific methods (Haynes 2007). As has been noted above, CAS is a promising line of research for this study as it provides a framework which accommodates the complexity of public sector procurement (Bovaird 2006), the engineering assets which are procured (Herder and Verwater-Lukszo 2006), and the emergent, changing nature of modern governance arrangements (Klijn and Teisman 2007; Meek, de Ladurantey and Newell 2007) which are required to care for such assets.

Systems' thinking is a way of understanding and investigating complexity, and CAS theory is now regarded as a strong candidate for providing a unifying notion of complexity (Chu, Strand and

Jelland 2003, 19). This paper will use CAS theory as a way of initiating and guiding thinking about the procurement of engineering asset management (Richardson 2005a). This is in line with other public policy research which posits CAS theory as providing a framework for analysis that is beyond a mere metaphor, and instead that it provides "a conceptual framework, a way of thinking and a way of seeing the world" (Mitleton-Kelly 2003, 26).

There is no one theory concerning CAS (Mitleton-Kelly 2003), but rather several theories arising from the studies in a variety of sciences. The following definition will be used in this paper:

> A complex adaptive system consists of a large and diverse number of agents that interact in nonlinear and adaptive ways. In a densely intertwined web of interacting agents … each agent is responding to other agents and the environment as a whole; it is continually adapting in the context of its relationships with other agents (Parsons 2007, 406).

While there are various perspectives on complexity, this paper will utilise CAS as a conceptual framework for examining engineering asset procurement.

While application of CAS theory to public policy arenas has been held to improve the understanding and performance of organisational systems, considerable work is needed to apply this concept to organisational contexts in general (Anderson 1999), and to public service arrangements, in particular (Daneke 2005).

Difficulties in applying CAS to procurement of engineering assets

Whetten (1989) argues that bringing a perspective into management from another field can be a fruitful way of developing new theoretical understanding. It is important to note in this regard that CAS theory originated in the fields of physics and biology. In physics for example "after three hundred years of dissecting everything into molecules and atoms nuclei and quarks, [scientists] … were starting to look at how those pieces go together into complex wholes" (Waldrop 1992, 16). Likewise in biology "where people had spent the last twenty years laying bare the molecular mechanisms of DNA, and proteins, and all the other components of the cell. Now they were also beginning to grapple with the essential mystery: how can several quadrillion such molecules organize themselves into an entity that moves, that responds, that reproduces, that is alive?" (Waldrop 1992, 16). Thus, CAS theory, which has its origins in physics, chemistry, biology and computational studies, may well provide novel and interesting perspectives which can improve our theoretical understanding (Whetten 1989), provide significant advancement in our understanding of procurement (Bovaird 2006) and provide insights into engineering assets such as rail (Klijn and Teisman 2007).

Mitleton-Kelly (2003) sounds a note of caution however, arguing that while the elements of systems of atomic particles may bear some resemblance to activities in organisations, there are also critical differences which need to be acknowledged – particularly the ability of people in organisations to reflect, learn and behave in ways that are not entirely predictable. Griffin and Shaw (2000) agree, contending that systems thinking is inappropriate for modelling the activities of human systems, as humans can choose between a variety of options, and their actions cannot be predicted with absolute certainty. Ball (2005) is more optimistic arguing that CAS thinking can provide a framework which enables comprehension of non-linear relationships typical in complex systems.

Introna (2003) has suggested that a way forward to the application of CAS theories to organisational research is to begin with some of the insights from the parent domain, and examine their applicability through empirical work, which could lead to novel understandings of social systems, and possibly ways of intervening in them. Eisenhardt (2002) argues that such constructs would still need to be tested in order to demonstrate their validity. Daneke (2005) agrees, noting there are significant opportunities for the application of systems thinking to public administration.

As noted above, CAS theory has been advocated as an important perspective which can be used to develop a better understanding of engineering assets (Smith and Stacey 1997), and government procurement (Bovaird 2007), and has been demonstrated as holding utility for the interaction between government procurement of engineering assets and the market (Hitchins 2003). These need to be tested, particularly given the relatively recent application of the theory to public policy problems (Klijn and Teisman 2007). As will be discussed later, the utility of CAS theory to understand government procurement of engineering asset management will be explored through a number of case studies.

Problem

There is considerable complexity involved in the procurement of engineering assets, and with the increased attention being paid to these assets by the public, government and industry alike, a study of the elements of the procurement system is timely. In addition, while various studies have examined specific aspects or elements of the procurement system, relatively few have examined procurement in its entirety – from a CAS perspective. This study will be of value to governments seeking a framework for making decisions concerning engineering assets, for industry seeking to engage with government, and for professional associations and education institutions which may wish to train staff in decision making processes under conditions of deep uncertainty.

Numerous authors have argued that CAS theory provides a powerful analytical device for examining and exploring complex phenomena (Parsons 2007, 407) for public policy issues in general (Klijn and Teisman 2007; Meek de Ladurantey and Newell 2007; Richardson 2006) engineering asset management (Rinaldi, Peerenboom, and Kelly 2001; Smith and Stacey 1997; Price and Akhlaghi 1999; Herder and Verwater-Lukszo 2006; Godau 1999), and the procurement of services such as engineering asset management (Klein and Teisman 2007). The application of CAS to social systems however, is fairly recent and there are many disagreements about how to apply these concepts (Parsons 2007). Considerable work is needed to apply CAS theory to organisational systems, particularly the operationalising and modelling of such concepts (Anderson 1999), and the testing of the theory in multiple cases in order to demonstrate and develop the application of the theory to public policy (Daneke 2005).

Statement of purpose

The purpose of this study then is to examine the procurement of engineering assets from a CAS perspective. Such analysis will seek to identify the agents, their roles and interaction; the rules which underlie the system, and the mechanisms by which such systems change and adapt, and are affected by their environment. Such research is exploratory (Babbie 2004) and is the first stage in developing a formal model of the procurement system of engineering assets. The purpose of this activity is in order to test the validity of CAS theory as a suitable framework for understanding the behaviour of government procurement from a systems perspective. By demonstrating the utility of CAS to explore the procurement of engineering asset management, the management, maintenance and long-term decision making for asset management is enhanced.

Given the relative newness of this perspective to organisational studies in general, and public policy in particular, the research will demonstrate the utility of systems thinking by examining a specific area of government activity (procurement) in a specific area of this activity (engineering assets).

Operationalising CAS research in public policy contexts

As noted earlier, an important process in developing an understating of a CAS is to develop a model of the system (Holland 1998). The development of a model of a public policy problem as a CAS, has been acknowledged as posing considerable difficulty (Rhodes and MacKechnie 2003). Chu et al. (2003, 27) agree arguing that the sheer complexity of a public policy problems, and the number of agents involved, makes the modelling of public policy areas as CAS very difficult to model.

As a way forward around this dilemma, and in order to apply the concept of CAS to procurement of engineering assets, it is prudent to firstly detail the elements, components and principles which are held to be part of all systems. This approach is particularly important if the CAS is used as a framework for thinking and analysis, not merely as a metaphor (Mitleton-Kelly 2003). As a first step, the core elements of a CAS must be described, and how this might be operationalised in this research project.

Firstly what is a public policy system? Rhodes and MacKechnie propose that:

> Public service systems consist of multiple organizations engaged in the provision of a specific set of goods and services that are of value to the majority of consumer-citizens (Rhodes and MacKechnie 2003, 61).

In order to apply the concept of CAS to procurement of engineering assets, it is prudent to firstly detail the elements, components and principles which are held to be part of all systems. As a first step then, the core elements of a CAS must firstly be educed. Once this has been achieved, an initial outline detailing how such elements might be operationalised in examining the procurement of engineering assets is undertaken.

Given the newness of the field (Parsons 2007) it is important to build on and expand existing empirical and theoretical foundations. Consequently, this paper identifies and those elements which are common in most papers on CAS as applied to organisations and public policy systems (eg Anderson 1999, Mittleton-Kelly 2003, Rhodes and Mackechnie 2003, Anderson et al, 2005, Klijn 2008). These are:

- Agents who interact according to schemata
- Self-organisation (also termed emergence)
- Co-evolution
- Adaptation, evolution and recombination

These elements are discussed in more detail below:

Agents who interact according to rules (schema)

Rather than approaching complex systems by reducing them to a set of causal variables, CAS models can show how complex outcomes flow from the interaction of agents based on a set of simple rules or schemata (Anderson 1999). The identification of agents is considered the first step in any CAS study[1] (Holland 1995). For organisational researchers, agents can be identified as individuals, groups, or coalitions of groups (Anderson 1999, 219).

For this research it is proposed that the main agents in a procurement system can be largely segmented into two groups according to their influence on the decision making process – direct and indirect. Direct agents include government agencies involved in the procurement process, and the firms involved in the planning, delivery and maintenance of specific assets. Indirect agents would be those who seek to influence the decision making process, but have no direct involvement in the decision itself. These include policy advisors, and political lobby groups. In terms familiar with public policy literature, these would be known as policy networks and delivery networks. An incomplete list is provided below:

Table 1 - Initial list of actors involved in procurement systems

Direct		Indirect	
Government	**Private**	**Government**	**Private**
Procurement units Clients Politicians	Principal contractors Sub contractors *(many of these are on pre-*	Policy officers Ministerial advisors	Policy networks Advocacy groups Lobby groups

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[1] Some authors in the literature use the term actors to refer to individual elements of a Complex Adaptive System. This paper will use the alternative term agent instead, as often individuals act as agents for their organisation.

	qualified supplier databases)		

A complete list would require full analysis of prequalification schemes, and research methods for eliciting the key agents in the system, such as snowball sampling in interview. The interaction between these agents is determined according to the 'rules of the system' which are discussed in the next section.

Interaction according to rules
Often an approach to studying organisations is to identify independent and dependant variables at the same level of analysis in order to demonstrate cause-and-effect relationships. CAS theory approaches this differently, by asking how changes in the rules of agents, or the interaction between agents, result in outcomes for the system as a whole (Anderson 1999). That individuals use rules to make decisions is reflected in the notion that agents have frames of reference or schemata (Rhodes and MacKechnie 2003) by which they interpret and evaluate information (Kiljn and Teisman 2007). These schemata include an understanding of how the world, people, organisations and procedures work (Wolf 2005, 187).

> Rules provide codes of meaning that facilitate the interpretation of ambiguous worlds. They embody collective and individual roles, identities, rights and obligations, interests, values worldviews, and memory, and thus constrain the allocation of attention, standards of evaluation, priorities, perceptions and resources (Olsen 2005, p.9).

From a symbolic interaction perspective individual agents struggle to control shared interpretation; roles and rules are negotiations and gambits in the struggle to define and construct meaning (Anderson 1999). For leading CAS authors such as Gell-Mann (1994) it is precisely this capability of being able to create schemata that distinguishes CAS from other complex systems such as galaxies. In fact, CAS can have many competing schemata which compete against each other – the ones that prove to be most salient are the ones that are reinforced (Holland 1995). From a public policy perspective:

> making sense of contemporary public administration then, requires and understanding of the complex ecology of institutions, actors, rules, values, principles, goals, interests, beliefs, powers and cleavages in which it operates (Olsen 2005, p7).

Holland (1995) contends that rules can be classified into two main types – rules which regulate the action of agents, and rules about the system itself. This point is echoed by Klijn (2001, 2007) suggesting that in public policy systems there are rules which focus on the policy arena itself (arena rules), and those which relate to the interaction of agents in a network (interaction rules). This can be demonstrated in the following table:

Table 2 – Main types of rules in policy systems (adapted from Klijn 2001, 2007)

	Description	**Aspects**	**Examples**
Interaction rules	Rules which regulate agents interactions	Access to policy game (who may enter the game, exit options, etc)	Pre-qualified supplier arrangements Institutional arrangements for procurement
		Interaction in policy game (what is permitted or not in interactions)	Conflict Information
System rules	Rules which regulate the setting or policy arena	Reality (what agents consider as core business or quality)	Identity of agents Product rules
		Payoff (costs and benefits for agents)	Status Evaluation criteria

		Positions (positions of agents and relations between positions)	Status Power

Like other elements of CAS theory, the notion of agent decision making based upon rules is not totally new to public management, as March and Simon have argued (1993, 8):

> The matching of rules to situations rests on the logic of appropriateness. Actions are chosen by recognizing a situation as being of a familiar, frequently encountered, type, and matching the recognized situation to a set of rules… The logic of appropriateness is linking to conceptions of experience, roles, intuition and expert knowledge. It deals with calculation mainly as a means of retrieving experience preserved in the organizations files or individuals memories.

Determination of the rules which guide the activity of agents would typically require interviews with the agents of the system. Applying this to procurement then requires an investigation of the rules about the procurement system and the rules of interaction within the system. As noted in the introduction there are a large number of decisions which need to be made in any procurement activity. Two key sets of rules relate to decisions concerning the institutional arrangements (interaction rules) involved in delivering the engineering asset, and in decisions concerning the engineering asset itself (system rules).

Interaction rules in procurement of engineering assets

As noted above, the determination about which agents are permitted to participate in a given arena is governed by a range of 'rules' about the system itself. Information concerning the role government agencies are permitted in the procurement process would be elicited from policy documents and interviews. The determination of which private agents are permitted to tender for engineering procurement would be elicited by examining policy documents, interviews and various mechanisms such as prequalification schemes.

System Rules in procurement of engineering assets

In terms of decisions concerning the engineering asset itself, there are three well recognised and competing rules for engineering assets: price, quality and cost. These rules are seen as competing, and project management literature argues that all three requirements cannot be achieved at any given time. For example, if the decision is made to deliver a 'gold-plated' solution (one of very high quality) then time and cost are likely to increase. Likewise, if time is of the essence, then quality and cost are likely to be affected. As noted above, validation and elicitation of additional rules would require interviews with key informants.

According to Holland (1995), from a relatively simple set of rules, a surprising amount of diversity is possible within a system. So establishing the key rules which influence procurement decision making are an important part of this research project. However, rules for the procurement of engineering assets (such as price, quality and time) can be seen to be in tension with each other. Agents must make choices between these alternatives, which is discussed in the next section.

Choosing between alternatives (also termed the fitness function)
As noted above, CAS theory argues that there are often competing rules in a system, and agents must choose between them. Choosing between alternatives is determined by what is termed the fitness function. Fitness functions govern how the agent will choose among alternative actions (Gell-Man 1984; Holland 1998). The most appropriate rules, (i.e. the ones that 'work') are the ones that tend to be reinforced – as they have a high level of fitness for agents in relation to the 'landscape'. A biological example is the choice of fight or flight for animals – the most appropriate choice is determined by what threat the organism is facing. This concept of a 'fitness function' is similar to the 'logic of appropriateness' outlined by March and Simon (1993), as organisations and individuals make choices based on past experience and learning about what the most appropriate action would be in a given circumstance. This concept of learning and reinforcement of rules is explored in the section on adaptation below.

In procurement, little research has been undertaken to date to understand how individual agents choose between differing procurement alternatives in government, with preliminary work suggesting that 'decision trees' are employed to make various procurement choices (Lædre et al. 2006). In this project, having determined the agents in the procurement system, and the rules they operate by, how the agents make choices between alternative procurement methods needs to be elicited, which is most likely possible through semi-structured interviewing. Thus the first key element of examining procurement of engineering assets from a CAS perspective is to identify the agents, their rules and how they choose between these rules.

CAS theory holds that the order in a system emerges from the interaction of agents based upon rules which are outlined in the next section.

Self-organisation (also termed emergence)
The structure and dynamics of a CAS are a result of choices by the agents, as they learn and adapt to actions of other agents (Albino et al., 2005). In other words there is no formal order imposed from outside of the CAS, and order emerges from the interactions between the agents at a local level (Stacey and Griffin 2005, 7). "Emergence is the term used in CAS theory to describe the phenomena of patterns at a higher level of abstraction that arise from interactions among lower level agents" (Rhodes and MacKechnie 2003, 63).

That a complex process can be self organising is not new in and of itself. Adam Smith (1971) introduced the notion of the 'invisible hand of capitalism' where markets were efficient yet were governed by laws of supply and demand, not government. What is relatively new is the application of this concept to management (Clippinger 1999, 2). Klijn and Teisman (2007) argue that notions of self-organisation have parallels in institutional theory with its idea that structures emerge from interaction of agents, as they interpret and use institutional rules. CAS models are inherently multi-level as the order is seen as an emergent property which results from lower levels of aggregate behaviour (Anderson 1999). No application of CAS to public policy has yet been able to demonstrate this multi-level nature of CAS to date. This research project will explicitly attempt to identify the multiple levels involved in engineering assets procurement as part of each case study.

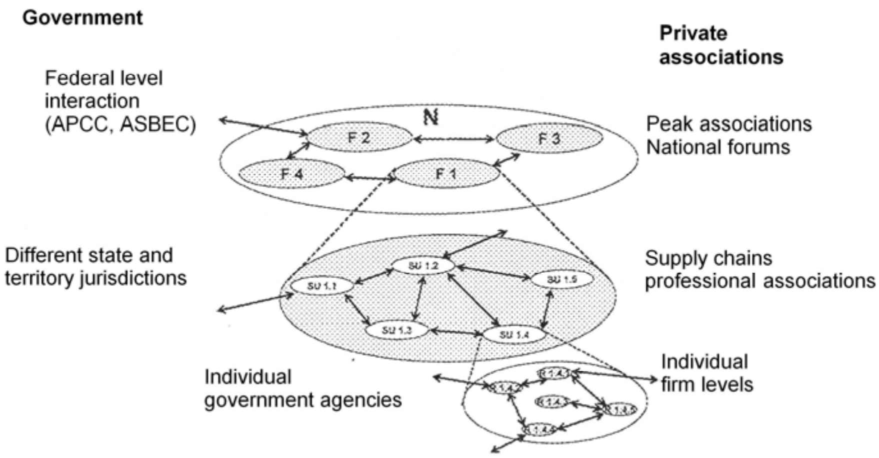
Daneke (2005, 95) argues that "the primary feature of social systems thinking is its focus on those elements that 'emerge' from the interactions of agents and institutions". Emergence is seen to be both a product of structures and relationships. For example, Auyang (1998, 176) argues that "emergent characters mostly belong to the structural aspects of the systems". Holland (1998, 121-122), on the other hand, argues that "emergence is above all a product of coupled, context dependant interaction. Technically these interactions, and the resulting system, are nonlinear. The behaviour of the system cannot be obtained by summing up the behaviours of its constituent parts … unless we take the nonlinear interactions into account". Consequently, emergence must study the analysis of the parts as well as the interactions between the parts as "we will not understand these complex systems until we understand the emergence phenomena that attend them" (Holland 1998, 4).

The structure of agents interacting in governmental arenas has been of growing concern to public policy researchers – particularly those research the various modes of governance: hierarchy, network and market (Brown and Keast 2007). Boisot and Child (1999) argue that these different organising arrangements are the main mechanisms[2] by which agents in CAS cope with complexity. After many years of research and theorising, markets, hierarchies and networks have been accepted as the fundamental, different modes of organising (Rhodes and MacKechnie 2003). Rhodes (1997) argued that the effective delivery of government services relies on ensure the right mix of these arrangements. Unfortunately, the right 'mix' for differing circumstances is difficult to identify. In this context, network arrangements are seen to be informal shadows of formal systems (Smith and Stacy 1997). The interaction between the formal (hierarchy) and informal (network) systems produces emergent order, which may or may not be in line with the intentions of those in authority (Smith and Stacey 1997). As Meek et al. (2007, p.24) have argued "administrative networks, shared governance, and co-production of public services developed in the conjunctive state, are real-world examples of the emergent properties of complex adaptive systems".

The implications of the concept of emergence for this research project are that lower levels of interaction result in order at the same level and also higher levels of order. Consequently the interaction of agents is held in CAS theory to result in higher levels of order and this 'emergence' of order should be explored as part of the research project.

Emergence of higher order structures in the procurement arena have emerged in Australia, with the formation of groups such as the Australian Procurement and Construction Council (APCC) and the Australian Asset Management Collaborative Group (AAMCoG). While the APCC does not have executive powers, it provides a forum for "knowledge sharing, intelligence gathering and has the information networks to draw on for formulating solutions" (APCC 2008), and was established following interaction from state and territory jurisdictions. Similarly AAMCoG exists to facilitate collaboration and knowledge sharing in the area of asset management (CIEAM 2006). Tilebein (2006) advanced a cogent explanation of the phenomena of emergence in organisations while studying supply chain management. An adaptation of Tilebein's (2006) model is given in Figure 2 below, and depicts emergent order as applied to government agencies and private firms and associations involved in procurement.

Figure 1 – Emergence of order in organisational contexts (adapted from Tilebein 2006, 1097).



Consequently the case studies would also need to explore the notion of emergence in the interviews – seeking to identify higher levels of order, often new institutions or organisations which have emerged from interactions at lower levels of action.

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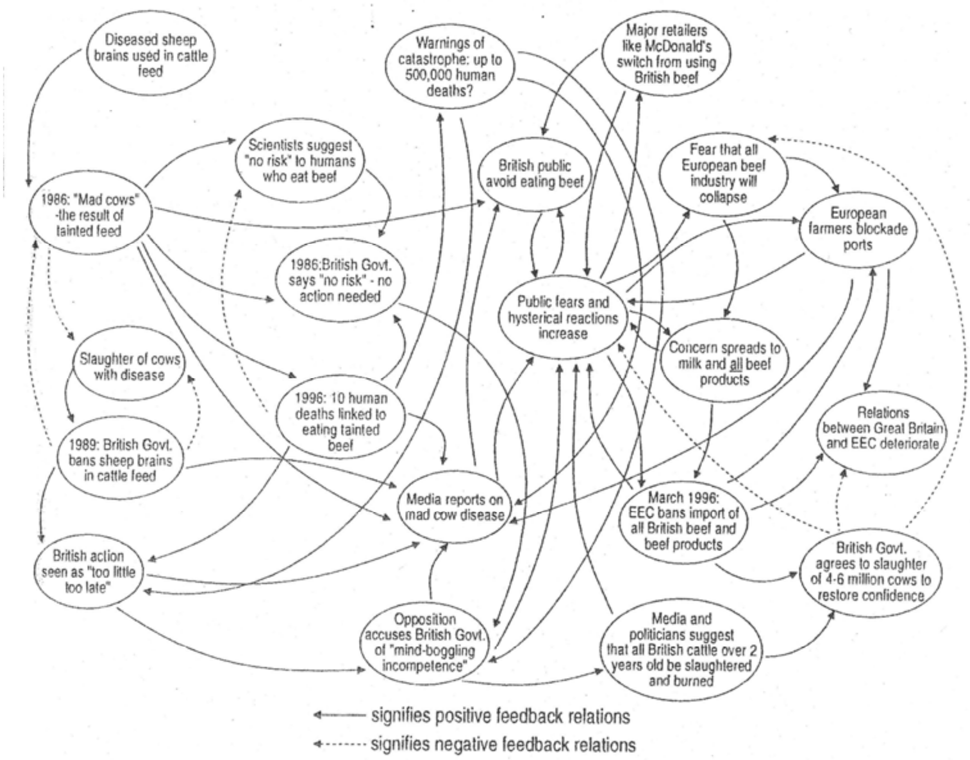
[2] Boisot and Child (1999) use the terms fief and clan in stead of the term networks. The term network has been retained as it is the term commonly used in a range of literatures (e.g. Rhodes 1997; Keast, Brown and Mandel 2006).

Co-Evolution

In a CAS, agents are seen as being interconnected so that the behaviour of an agent is influenced by the behaviour of other agents in the system. As one agent changes, so does the other – hence the understanding of co-evolution. It is this interconnectedness of agents which distinguishes CAS models from other systems models. For example "in systems dynamic models, *variables* are connected to each other by feedback loops; in CAS models, *agents* are connected to one another by feedback loops" (Anderson 1999, p. 219 *italics* in the original). The notion of co-evolution has particular purchase for decision making in networks "where experiences and choice influence each other because of learning processes" (Klijn and Teisman 2007, 9). Morgan (1997) refers to this process as mutual causality and provides and example in the "mad cow" problem which decimated an industry in Britain.

Figure 2 – How decisions by one agent influence other agent's decisions (Morgan 1997, 279)



The idea that agents, their rules and their interactions co-evolve in CASs has been outlined above. One way of applying this to procurement system is that in organisations and markets, the least-fit element of systems tend to be eliminated – organisations replace their least efficient members, and least efficient firms in an industry tend to go out of business (Anderson 1999). A new agent drawn at random is likely to have a higher average fitness that the weak one replaces, which sets of changes in relationships between agents and can cause a cascade of changes in co-evolutionary adaptation in the system. With new actors, or new rules, or new relationships between actors, this causes a cascade of changes in the system.

Consequently, changes to the participants in a system, or their rules would need to be examined through interviews and reference to secondary data such as prequalification schemes in order to explore the concept of co-evolution.

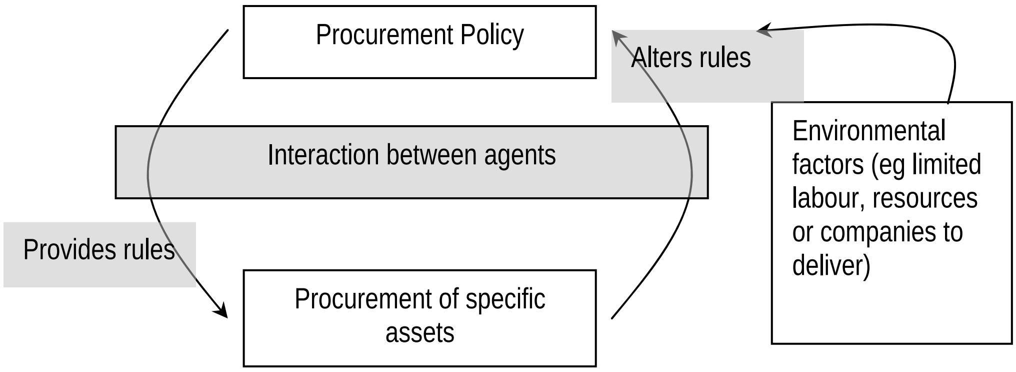
Adaptation, Recombination, and Evolution

Adaptation in CAS occurs due to changes in the environment, the choices of agents and often a dynamic feedback between these two. When the environment of the system changes, so does the behaviour of it agents and as a result, the behaviour of the system as a whole – in other words – the system learns and adapts to the new environment (Lewin and Regine 2003). CAS also evolves over time through the entry, exit, and change of agents, as well as changes in the linkages between agents (Anderson 1999). The structure and dynamics of a CAS are a result of choices by the agents, as they learn and adapt to actions of other agents (Albino et al., 2005). Chapman (2000) argues that learning is a critical issue which is enabled by systems approaches to policy problems.

Research into engineering asset procurement from a CAS perspective therefore needs to examine how the procurement system (the agents, their relationships, and/or the rules) have changed over time, due to either the choice of agents, or changes in the environment.

In order to demonstrate the concept of self-organisation for procurement policy is perhaps best illustrated by drawing on extant research of the author, together with the underpinning adaptation and co-evolution of systems. In Furneaux et al. (2006) a summary of variant procurement approaches for public works in Australia was advanced. In the course of completing this research, it was evident that the procurement system in many states had recently changed from that which followed the widespread introduction of contracting out in Australian jurisdictions, and this was largely driven by interaction with construction firms and client agencies, or by changes in the environment. Figure 1 provides and initial conceptualisation of this:

Figure 3 - Initial conceptualisation of Policy Emergence



Summary

Following Rhodes and MacKechnie (2003) it is proposed that an investigation into CAS in public policy might be operationalised by firstly undertaking a description of the agents of the system. Identifying who the agents are, and the nature and level of connections between agents, are key building blocks to understanding the nature of a system and how it operates and helps to identify the state of the system (Holland 1995). This is likely to be achieved by starting with the list of suppliers who are pre-qualified to deliver a particular type of engineering asset, and the government agencies which are responsible for the procurement of such assets. The next step is to examine the schemata (or rules) by which the agents make decisions, the way agents decide which decisions to take notice of, and the process by which rules change (Rhodes and MacKecknie 2003). An example of this might be under what circumstances an alliance methodology is chosen for construction of an asset. Investigation of policy documents suggests that alliance contracts are often used in highly complex infrastructure projects such as dams (New South Wales Treasury 2005), although this does not explain why private firms would decide to participate in such arrangements. A related activity is to examine how agents choose between different options (Holland 1995). An example of this might be to ask agents how they decide to tender or participate in design-construct arrangements, as opposed to design–construct-maintain arrangements. The final steps would be to identify how the system acts in relation to other systems in the environment, and how the system adapts and learns over time (Smith and Stacey 1997). An example of this is the recent changes of many smaller government agencies who recently centralised procurement in response to changes in the environment (Furneaux, Brown, Allan, McConville, McFallan, London and Burgess 2006b).

These key areas are stated below as formal research objectives.

Research aim and objectives

- The aim of this research is to use CAS theory as a framework to develop a richer understanding of engineering asset procurement systems.

In order to deploy CAS theory in this context, it is necessary to identify the key elements of such a system and how they operate. As outlined in the literature review above, these include:

- Identifying the central agents of the engineering asset procurement system
- How do these agents elements interact
- The rules which guide decisions made by these agents
- The tension(s) between rules and agents
- How are these tensions resolved? (which one 'wins' and why)
- Changes (emergence) in the engineering asset procurement system to changes in the environment or decisions of agents?

Significance

Yin (2003b) suggests that there can be three areas of significance for research: contribution to knowledge in the area, to policy and to practitioners.

To knowledge in the area
Various authors have called for the application of CAS perspective to understanding policy processes (Bovaird 2007; Klijn and Teisman 2007; Meek, de Ladurantey and Newell 2007; Richardson 2006; Sanderson 2000; Stewart and Ayres year) although empirical investigations are few.

> Through Complex Adaptive System models and empirical verification, the black box of public service systems may become more transparent, thereby progressing our understanding of the link between agent decisions, agent interactions and system outcomes (Rhodes and MacKechnie 2003, 80).

By demonstrating the utility of CAS theory in explaining the outcomes of procurement systems, an alternative theoretical model of policy development processes within government can be developed.

To policy
The implications for policy are far reaching. Many procurement approaches assume simple relationships between principal and agent, and consequently may not take into consideration adaptation and change in the system itself. A better understanding of the procurement of engineering assets is likely to lead to a better understanding of how to manage the problems encountered within these systems (Smith and Stacey 1997). While not seen as an intervention in and of itself, by developing a model of the system it is possible this can lead to changes at a policy level, as the influence of various forces becomes apparent (Wolstenholme 1992). Mass (1986) has argued that models of system are sufficiently accurate, they can move decision makers towards a deeper conceptualisation of the impact of their policy choices, and thereby lead to a change in their choices. Improved procurement choices should result in enhanced economic and social benefits for stakeholders.

To practice
Similar to the policy implications, an improved understanding of the nature and dynamics of a system can lead to improved outcomes for participants as assumptions are tested and improved and improved understanding can lead to better ways to address problems encountered in the system (Smith and Stacey 1997). As noted in the problem section above, some of the key problems affecting the procurement system at the moment are rising costs, and lack of skilled labour. The private sector should also benefit as depiction of the procurement system will enhance their participation as agents in that system – particularly the rules by which the system operates, and how change occurs in the system.

By examining engineering asset procurement from a CAS perspective, it is thus anticipated to advance theoretical and practical knowledge of how such arrangements can be governed and effectively managed.

Methodology

As noted in the preceding sections, this research project seeks to apply CAS thinking to research into the procurement of engineering asset management. Given the note of caution raised by Mitleton-Kelly (2003) concerning the importance of testing the applicability of the assumptions of CAS theory to public administration the overarching methodological approach to the research will be that of a series of qualitative case studies, which will examine separate examples of the procurement of engineering assets. Each case study will answer the research objectives outlined above by seeking to identify each of the agents in the system, how they interact with each other, the rules which underpin their behaviour how the system adapts and changes, and if higher order emergent structures can be identified. In order to explore these elements, initially a series of interviews will be undertaken with key informants to identify their goals, rules, and interactions with other agents. From these initial sets of interviews, initial models of the system will be developed. A series of focus groups with key informants will then test and refine these models, in order to explore the functioning of the system as a whole, particularly interaction, adaptation and feedback within the system, and how the system and its rules change over time. Once each of the case studies has been completed, cross case comparisons can occur to elicit similarities and differences between the cases. These methodologies are discussed in detail below.

Case studies

Case studies provide for in-depth analysis of a particular issue or technology as it impacts an organisation or industry, and can provide strong recommendations for improvements in theory, technology or policy. Case studies in the area of policy have been called for as a way of advancing public policy practice (Osborne and Brown 2005, Stake 2005). Given the dearth of existing work undertaken in CAS research for public policy (Klijn and Teisman 2007) an exploratory case study methodology (Babbie 2004, 87–88) is appropriate. This is because a series of case studies can develop the application or understanding of theory to an area (Eisenhardt 2002) such as has been advocated for CAS and public policy (Daneke 2005).

A case study is “a method for learning about a complex instance, based on a comprehensive understanding of that instance obtained by extensive descriptions and analysis of that instance taken as a whole and in its context” (U.S. General Accounting Office 1990, cited in Mertens 2005:237). The objective of conducting multiple cases is to examine particular phenomena in multiple contexts in order to understand how, when and why it occurs (Huberman and Miles 1994). Multiple cases can enable powerful explanation of a particular process if the research is carefully ordered (Huberman and Miles 1994). Additionally, the multiple case studies enhance the generalisability of findings back to theory or policy (Yin 2003a), due to the fact that the same phenomena are investigated in multiple contexts (Schofield 2002).

Therefore multiple case study approach for examining systems such as the procurement of engineering assets, has both been called for by leading authors and appears appropriate. Such an approach is held to have utility due to the lack of research in the area and have been explicitly called for as a way of processing understanding of complex adaptive systems in general (Holland 1995) and also in the application of CAS theory to specific industry contexts (Herder and Verwater-Lukszo 2006). A multiple case study framework will enable a better understanding of the phenomena of engineering asset procurement from a CAS perspective.

Sample

Sampling within qualitative research is not necessarily based on random sampling, as often a specific instance or example is being examined in detail. For this project, selection of cases will be theory based – as the issue is to find examples of policy situations in which CAS theory can be used to elaborate and examine these cases (Miles and Huberman 1994).

In order to gain access to specific cases, the partners of the CRC funding this research project, the Centre for Integrated Engineering Asset Management (CIEAM), will be approached initially. These include:

- Defence: ASC, DSTO,
- Electricity: Delta Electrical, Electrical Supply Authority
- Water: Sun Water
- Other partners: Queensland Rail, Rio Tinto, ANSTO, Commerce Queensland.

Given that the subject of the cases are engineering assets, it is quite likely that different methodologies or processes are in place for procuring different types or classes of assets. For example, evidence suggests that the procurement of dams in South East Queensland is almost always delivered via an alliance contract, whereas the procurement of public buildings would not. Major roads contracts are often delivered via competitive tendering arrangements, although alliance contracts have also been used in specific instances; whereas smaller maintenance contracts are almost always via sole invitee arrangements (Queensland Department of Main Roads 2006). For larger assets such as certain military equipment or types of power station, it is also likely that there are very few suppliers able to tender for specific types of assets, which may in turn affect the procurement process. Consequently, cases shall be selected in order to represent a number of different asset classes (such as defence, transport - roads and rail, and utilities - water and electricity). As examples of case studies would be the procurement and establishment processes involved in the South East Queensland water grid, the recent privatisation of electricity delivery in South East Queensland, or defence procurement.

In attempts to resolve the water crisis, a large number of discrete projects are underway which are designed to work together in order to collectively improve the supply of water to Brisbane, one of which is the provision of a desalination plant. This case study explores the use of multiple contracts, and multiple assets to address a specific problem. A second case study is the recent contracting of electricity supply in South East Queensland, where government retained the generation of electricity, but contracted the supply of electricity to private firms in order to fund the ongoing water crisis. Another pertinent case study is the procurement of the new frigate for the Australian navy, which involves a single, large, long term contract, and the investment of significant amounts of capital into the development of economic and social infrastructure around the naval base in order to promote industry development (Furneaux and Brown 2007b). The different type of actors involved in each case study and the role they take, is outlined below:

Table 3 - Types of actors involved in potential case studies

	Water (in SE Queensland)	**Electricity** (in SE Queensland)	**Defence**
Production	Both private and public actors	Public	Private
Supply	Public	Private	Private
Deployment (applies to defence only)			Public

Sampling within each of the case studies would identify all of the key agents in the CAS. Rule-based action and matching of appropriate action to recognised situations on the other hand, is seen as the province of experienced decision makers – experts, who have developed capability in a particular area over time (March and Simon 1993, 11). Snowball sampling of key informants is seen as particularly important for research involving policymakers (Farquharson 2005). The snowball sampling approach is useful for exploring sets of relationships, as agents in the system are aware of each other, and thus will not exclude any important agents (Milward and Provan 1998). Agents will be identified from existing information and asked to nominate additional organisations not on the original list, thus following a snowball methodology. An example of this would be in the prequalification supplier arrangements which determine who is eligible to contract for the provision of particular engineering assets.

The sample size of interviews in qualitative research is determined by theoretical saturation – once there is no new data coming forward in interview or in focus groups, then there is a probability that theoretical saturation has been reached (Bryman and Bell 2001: 372).

Unit of analysis

Typically in organisational studies the unit of analysis focuses at a specific level, as an organisation is viewed as a level above the individuals that form it; and the organisation is in turn below economic and governmental forces which are seen as above and beyond the organisation and the individuals which comprise it (Stacey and Griffin 2005). For systems analysis such discrete analysis is problematic as "processes within an organization shape the external world, even as it is being shaped by that world" (March and Simon 1993, 17). A hallmark of systems research is the exploration of multiple agents and levels of action within a system (Holland 1995). Hitchins (2003, 80) argues that all systems are in fact comprised of subsystems so every system is a "system of systems". Holland states this another way by noting there are multiple levels within systems (Holland 1998, 9) and higher order systems are built up from a combination of lower level systems (Holland 1995). This concept of emergence was discussed in detail above. Given that all of the different elements identified above appear to interact with each other, and influence each other, then not only does this fit with the description of what a system is and how it operates, but also helps to solve the unit of analysis question.

Systems dynamic models typically seek to examine the output of the system as a whole, rather than the individual actions of individual agents (Robertson 2005). Lewin and Regine (2003, 169) argue instead that the correct unit of analysis for systems research is the interactions or relationships between people and between organisations. Hitchins (2003, 34) notes that government systems are both frameworks of rules created by humans to regulate human behaviour; as well as groups of people who design and implement change and are changed by the systems they have helped to create. Thus the study of systems must study the parts, as well as the interactions between the parts (Holland 1998, 13). Holland (1995) suggests that at least two tiers of analysis are needed in order to understand systems of any sort – one which models the set of relationships and the flow of resources between agents at one level, and the other a higher level which sets out the rules for interaction and adaptation of the system itself.

Consequently the unit of analysis is the procurement system – the range of agents, the external environment, the rules by which decisions are made – all of the elements of the system which were noted in the literature review. It is contended that these factors – the environment, the interaction rules and rules about the system, together with the roles of individual agents and emergent structures are all important to understanding the system, and to explore the set of relationships, as well as the rules and the adaptation involved in the CAS.

The following section outlines research tactics in the areas of systems thinking and system dynamics research, which it is proposed will enable effective answering of the research questions – and is particularly important for the identification of the various agents in a system, how they interact and how they adapt and change. Secondly the sections that follow provide an overview of how to develop models of systems through focus groups, which is held to greatly improve the validity of research into systems, and therefore enhances the understanding of system dynamics.

Systems dynamics research

Anderson (1999) argues that complexity thinking provides a significant and powerful new perspective for researchers to examine decision making within organisations. As noted above, CAS research has been advocated as a fruitful framework for examining decision making in engineering asset procurement. Researchers who examine complex systems typically attempt to model the dynamics of the system under investigation (Pidd 1996). A key reason for this is that the process of model building examines and helps to explain the complexity of the system which is being examined (Holland 1998, 4). Such a model would depict the behaviour of the system (Hitchins 2003), and decision-making within the system (Anderson 1999). This raises the question as to what is a model, as understood from within the complexity perspective of management. A succinct definition of a model which shall be used in this research:

> A model is a representation of reality which abstracts the features of the situation relevant to the question being studied. The means of representation may vary from a set of mathematical equations or a computer program to a purely verbal description of the situation, in which judgement alone is used to assess the consequences of various choices. (Quade and Boucher 1968, cited in Hoos 1981, 40).

As with most business research, models of complex systems can occur in a variety of modes and methods, and can be divided into quantitative and qualitative approaches (Cohen 1999). Each has their own strengths and weaknesses, and applicability to different situations and contexts. An overview of qualitative and quantitative approaches to modelling CAS and their relevance to the examination of the procurement of engineering assets follows.

Quantitative and qualitative approaches to modelling the dynamics of CAS

Various authors have approached the computer simulation of policy outcomes from a quantitative perspective (e.g. Mass 1991). One reason given for this is that qualitative models can become too ambiguous and difficult to simulate manually (Sterman 1994). Against this, Hoos (1981) is strongly critical of social scientists developing computer models as though these are definitive representations of real world problems, and suggests that inevitably important factors under investigation will be neglected, thereby reducing the validity of the model of the system being developed. Emery (1981) also argues that mathematical models of complex systems ignore the vast complexity of human action and choices.

Wolstenholme (1992) argues that having completed a qualitative system dynamics model, there is no pressing need to convert the model to a computer based application – as the diagram itself, if done properly, can promote thinking in its own right. Richardson (1999) has argued that the general trend in systems dynamic research is towards qualitative mapping approaches by themselves, without quantitative simulation. Coyle (2000) agrees arguing that a rigorous qualitative description of a system might be of significant value in and of its own right as it would lead to a better understanding of the problem.

Given that research into nascent or little understood phenomena should utilise a qualitative, explorative approach to the research problem (Edmondson and McManus 2007), this project will use a qualitative approach to model the dynamics of engineering asset procurement as a CAS.

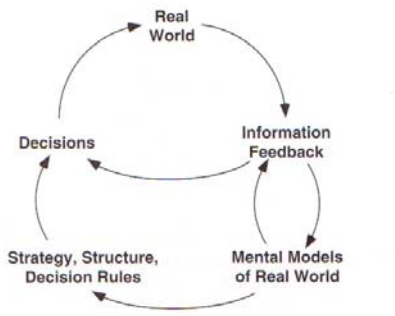
Qualitative approaches to the modelling of systems, however, come in various sub-types, with Soft Systems Methodology (Checkland 1981, Coyle and Alexander 1997), system dynamics (Forrester 2007) and complexity theory (Klijn and Teisman 2007) all prevalent in studies of organisational systems (Jackson 2003).

Soft systems methodology (SSM) is held to be an effective tool which can be used to model a system (Bergvall-Kåreborn, Mirijamdotter, and Basden (2004). However, Stacy and Griffin (2005) argue that SSM is intractably linked to participant observation and action learning methodologies which seek to change the system in which the research is a part. Given that the research problem being explored is focussed on exploratory research, then qualitative approaches which explicitly set out to change a system from the outset, such as SSM, would not be appropriate. Instead research approaches which explore complexity and the dynamics of adaptive systems will be used.

Complexity and systems dynamics approaches

Systems dynamics approaches do not set out to attempt to change the system which is being modelled. However, the very process of undertaking the research will generate causal loop diagrams (discussed below) to participants. Mass (1986) argues that if these models of the system are sufficiently accurate, it may move decision makers towards a deeper conceptualisation of the impact of their policy choices, and thereby lead to a change in their choices. This feedback process is a process termed double loop learning, which is outlined in Figure 1 below. Figure 1 is in fact an example of a causal loop diagram which is a central element in complexity thinking and system dynamic models.

Figure 4 - Double loop learning and decisions (Sterman 2000, 19)



Causal loop diagrams

Causal loop diagrams were used to depict the basic causal mechanisms that were seen to underlie behaviour of agents in the system (Randers 1973, 1980). Hitchins (2003) argues that causal loop diagrams help to depict complex problems – particularly the elements, and behaviour of systems. Causal mapping is an important way of depicting the relationships and influences between parts of a system (Brock, Chesbro, Cragan and Klumpp 1973), and both Hitchins (2003) and Sterman (2000) argue that causal loop diagrams are important tools for demonstrating feedback in systems. Miles and Huberman agree, stating:

> A causal network is a display of the most important independent and dependant variables in a field of study and of the relationships among them (1994, 153)

Causal maps can be built from the ground up, or commence from an initial set of assumptions, and can be amended following information provided by informants, with the latter generating results at a faster rate (Miles and Huberman 1994). Causal maps can be used for both within case analysis and between case analysis (Miles and Huberman 1994), which is important for this study, as it explores multiple cases of engineering asset management and maintenance procurement systems. An example of a causal loop diagram was provided in the literature review in order to explicate the issue of co-evolution (Figure

Wolstenholme (1999) argues that qualitative modelling of systems dynamics through causal loop diagrams enables participants to externalise mental models of the system in question. Cognitive mapping is an important approach to understanding and depicting the mental models of decision makers (McDonald, Daniels and Harris 2004). How these mental maps of CAS might be elicited is discussed below.

Mental maps and models of complex systems

Farsides (2004) argues that cognitive mapping is a process which aims to develop a better understanding of people's worlds and how they conceptualise the various concepts which might comprise such a world. Morecroft (2004) argues that mental models are important for developing an understanding of how pieces in a system fit together, how the parts interact with each other. Anderson, Meyer, Eisenhardt, Carley and Pettigrew (1999) suggest that it is important to map agent's mental models in complex systems, together with the ties that connect them together. Edkins, Karul, Maytorena-Sanchez and Rintala. (2007) note that cognitive mapping tools are extremely valuable in mapping complex managerial environments, suggesting that that NVIVO for data coding and Decision Explorer for the diagrammatic representation of relationships between concepts. Brock et al. (1973, 50) argues that mapping of mental models should include: the agents within a system; the relationship between these agents; their goals; the rules by which they make decisions; the outcomes of the interactions between agents in comparison to their goals.

The specific methodologies advocated for garnering this information include semi-structured interviews, content analysis of the interviews and concept mapping (Farsides 2004; Edmondson and McManus 2007). Vennix (1999), Luna-Reyes, Martinez-Moyano, Pardo, Cresswell, Andersen, and Richardson (2006) and Ackermann and Eden (2004) agree but suggest that in addition to interviews and qualitative text analysis, mapping through focus groups enables generation of more complex maps as respondents are able to see each other's models and adapt the final diagram. This process is similar to that advocated by both Ford and Sterman (1998, 317) and Vennix and Gubbels (1992) who recommend eliciting the mental models of multiple agents through a staged process of firstly conducting interviews, mapping the concepts by researchers, and then checking the models with focus groups of experts in order to further test and refine the models.

Thus eliciting experts' mental maps requires the use of interviews and focus groups which fits well with a qualitative case study approach outlined above. Such mental maps are vital to understanding engineering asset management procurement from a CAS perspective – particularly the dynamics of the system – its agents, their rules and how the system interacts.

Stated succinctly, the process for developing an understanding of CAS such as the procurement of engineering asset management for this project will be:

- Conduct interviews with key informants and gather relevant documents on the process under examination
- Identify key agents, goals, interactions, rules, and outcomes of interactions from these sources
- Develop initial causal loop diagrams
- Conduct focus groups to check and refine the models
- Conduct cross case comparisons of the cases

These steps are discussed in detail below.

Data collection instruments and rationale

In order to discover the elements and to model the CAS noted above, specific methodologies will be used to gather data:

- Policy analysis and evaluation will identify the critical elements of engineering asset procurement, particularly the established 'rules' which might guide the procurement process
- Semi-structured interviews will be utilised to develop a fuller understanding of the range of agents involved in the system, the roles they play, and the rules that they operate by.
- Focus groups will be utilised in order to explore the mental models arising from the initial set of interviews in order to test and refine the concept and model of procurement as a system. Any differences between the rules available in the literature, and the rules of individual agents will be explored and commented on.

As outlined above, such a process enables the eliciting the extent, nature, and functioning of CAS such as engineering asset management, together with the rules used by agents to make decisions. This project also uses multiple case studies, which Yin (2003b) argues should include multiple sources of evidence. Multiple methods of analysis are typical in case study research and allow for triangulation of data which is important in qualitative research to enhance validity (Eisenhardt 1989: 537). In this case the original data set will be derived from the policy documents which explore the existing understanding of procurement as set out in practitioner and academic literature. The interviews will generate a set of raw data, exploring roles, relationships and rules involved in the procurement process. The primary data and the secondary data will then be examined, compared and contrasted. An initial model of the procurement process which arises from the two data sources will then be presented back to a focus group of nominated experts in the procurement process. The validity of the model will be explored with the focus group in order to test for situations and circumstances which might guide the use of a particular rule in a given situation, for a particular asset, and not in others.

The specific methodologies of interviews and focus groups are discussed in detail below, together with triangulation between data sources.

Semi-Structured Interviews

Semi-structured face-to-face and telephone interviews will be conducted with all agents involved in the procurement of a particular engineering asset – clients, central agencies, lead contractors, sub-contractors, funding bodies, and policy activists. Interviews provide the initial set of information about the CAS being examined, particularly the agents, their goals and their interactions with other agents. General information about the procurement of engineering assets system would also be generated from the interviews. Semi-structured interviewing was selected as it provides for cross-case comparability (Bryman and Bell, 2001: 346), and is important when conducting exploratory studies – particularly in order to find out what is actually happening in practice (Saunders, Lewis and Thornhill 2000: 245). Mitzberg (1979, 587) argues that semi-structured interviews are an important method to use in qualitative research such as is being undertaken in this project:

Semi structured interviews provide key information about policy processes, as they allow for the telling of individual perceptions and understanding (Marinetto 1999: 72). Interviewees will be provided with opportunities to review and correct interview summaries, by checking the data for accuracy, thereby strengthening the internal validity of the research (Mertens 2005).

The information provided in the interviews will then enable the generation of initial model of the CAS being examined. These initial models will be tested and further refined in a series of focus groups.

Focus Groups

Focus groups are important in qualitative research as these allow for variance in the interpretation of issues by participants, and to understand the ways these differences are resolved and consensus is built (Mertens 2005). In a group interview the researcher acts as facilitator and manager of the discussion (Saunders, Lewis and Thornhill 2000: 268). Focus group techniques have been noted above as an important method for testing and improving the mental models of engineering asset procurement systems developed from initial sets of interviews (Ackermann and Eden 2004).

The sample size of focus groups would be four to six groups per case study, with 7 to 10 people per group. These numbers are considered acceptable for answering research questions in focus groups, although the numbers can be adjusted for specific research questions (Mertens 2005). Approximately four to five questions can be asked effectively in a given focus group, as opportunity for each member to participate is encouraged and discussion amongst group members will limit the amount of topics that can be covered in a single session (Cavana, Delahaye and Sekaran 2001).

As noted above, the purpose of the focus groups is to explore the initial models of CAS developed following the interviews, and to allow for the further development and refinement of the models. This process is held to improve the validity of models (Miles and Huberman 1994).

Individual informants will be de-identified and any commercial in-confidence information will not been divulged. All interviews and focus groups will be conducted in confidentiality, and the names of interviewees will be withheld. The names of government departments, government reports, and most government policies will not be obscured as most of this information is already freely available, either on the Internet or in public libraries.

Triangulation

Triangulation can be used between the various data sources in order to clarify meaning, verifying the repeatability of the observation or interpretation (Stake 2005). Triangulation can enable a holistic understanding of the problem being investigated (Jick 1979), and minimises the risk of potential bias that may arise if only one methodology was used (Scandura and Williams 2000, 1249). This project will undertake triangulation of data and method (Patton 1987, cited in Yin 2003b). Data triangulation uses data from different sources in order to triangulate and look for differences. This is particularly important for model building processes. The sections above have outlined how the use of interviews and focus groups enable triangulation between methods in order to develop and test models of the system. Additionally, Yin (2003) argues that data can be triangulated between cases, thereby further enhancing generalisability.

Data analysis

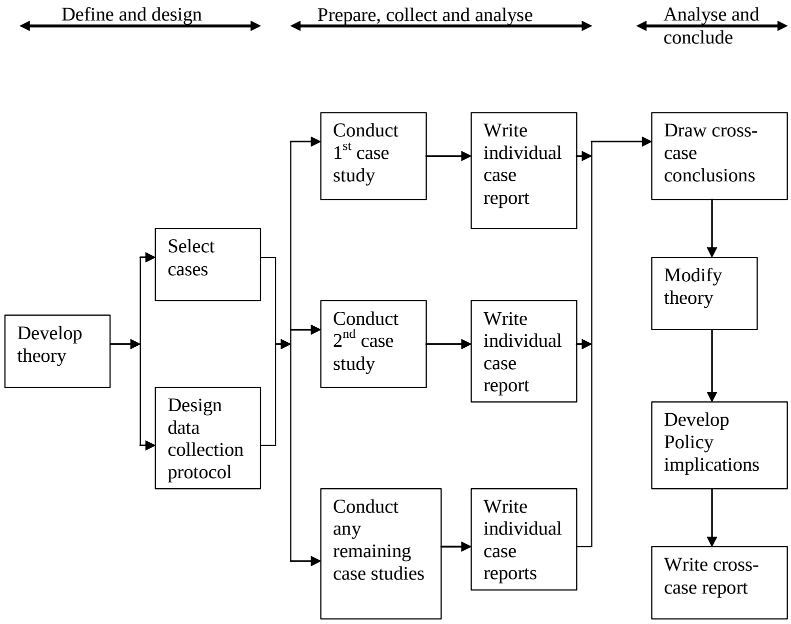
Huberman and Miles (1994) argue that the first step in analysis is to provide a descriptive outline of what is happening in the case. Modelling engineering asset procurement from a CAS perspective, entails the description of the system, its' agents and their interactions, and the dynamics of how each system operates. The extant literature and interviews will form the basis for the initial set of causal loop diagrams. The development of these causal loop diagrams follows a pattern of inductive reasoning which firstly observes the system, analysing patterns and themes, formulating relationships and then develops a theory (Cavana, Delahaye and Sekaran 2001), which in this case is a model of the system. Triangulation can be used between the various data sources in order to clarify meaning, verifying the repeatability of the observation or interpretation (Stake 2003), which in this case is between the secondary data and the primary data. An iterative approach is followed where data is analysed until no alternative explanation can be found (Bryman and Bell 2001: 426).

Within case analysis is the first step in coping with a large amount of data which can be generated in case study research (Eisenhardt 2002). Such analysis is aided through data displays which condense key incidents or elements of the study. The provision of a dialogue between ideas and evidence is important in the analysis phase, as it enables the opportunity of seeing relationships, themes, patterns and clusters of data, and affords the opportunity of developing explanations about such data.

The initial models developed from document analysis and interviews will then be discussed in a focus group setting where the assumptions, relationships, rules and roles of each element of the system are examined and modified. In this study, this would require the structure and dynamics of each CAS to be elaborated, tested, refined and improved. The emerging constructs from the case studies of each system, are tested in relation to each case and whether they hold or are different for each case thereby strengthening the internal validity of the research (Eisenhardt 2002). The important process is to test for the validity of the model in the minds of the key informants who operate within the system on a daily basis.

Once each case study has been finalised, cross case comparisons are possible, which strengthen the external validity of the research (Huberman and Miles (1994), and facilitate better understand of CAS (Holland 1995). During this phase of the research, there is a search for patterns of similarity or difference between cases, together with an iteration between data and emergent theory which is strengthened and built from multiple cases and multiple data sources (Eisenhardt 2002). This process has been depicted by (Yin 2003b: 50).

Figure 5 – Process for implementing a case study (Yinn 2003b: 50)



As the application of CAS theory is novel, the applicability of the theory to specific instances of engineering asset procurement will enable the testing of the theory in multiple contexts. By testing CAS theory in multiple cases within a single research project, cross case comparisons can be undertaken which enable the testing and building of theory (Daneke 2005).

Summary of data collection stages

A summary of how these methodologies could be utilised in the research project is outlined below:

Table 4 - Summary of data collection strategies

	Literature review / Qualitative text analysis	**Interviews**	**Focus groups**	**Comments**
Phase 1 – Identification of elements, agents, rules, roles and tension	Identify factors in literature Gather policy documents	Initial interviews to elicit rules, roles and relationships of agents in the system		Collate data for the development of the initial models.
Phase 2 – Development of theoretical model				Initial analysis, synthesis and comparison of data. Development of initial model.
Phase 3 – Validation / improvement of the model	Recheck the literature for any missing elements	Interviews on specific case studies to clarify issues.	Focus groups to clarify and improve the models	Testing and modification of the models
Phase 4 – cross case comparisons	If needed	If needed	If needed	Cross case comparison of the data, looking for similarities and differences between the cases in order to build theory

Data depiction

Displaying of data and analysis of data are often relates, as robust explanation and depiction is likely to lead to better analysis. The literature on researching systems provides useful insights into the display and depiction of the agents in a CAS, and how they interrelate.

Matrices and charts

Components of the system need to be identified and explained – importantly that there may be sub-components which act relatively independently of each other, and yet have an impact on the outcome as a whole (Brock et al. 1973, 62). N^2 charts are forms of matrixes which are useful for depicting complex sets of relationships and interaction between different components of a system, such as the sharing of resources (information or financial) (Hitchins 2003) (see Figure 3 below).

Figure 6 – An example of a N^2 matrix (adapted from Hitchins 2003, 145)

Sub-system A	0				
0	Sub-system B	0			
		Sub-system C	0	0	0
		0	Sub-system D	0	0
			0	Sub-system E	0
			0	0	Sub-system F

Gill (1996) argues that by firstly eliciting relationships from interviews and placing these onto a matrix form of diagram, relationships between parties can be identified. These can then be turned into system dynamics diagrams, causal maps, or other forms of network diagram. Richardson (2005) notes that from these matrixes it is possible to build network graphs of relationships between agents in a network, which will enable the understanding of the set of agents in a CAS and how they interrelate to each other.

Developing of models through iteration

As noted above, once the initial models have been developed, it is important to gain feedback from informants on the model under development in multiple times (Miles and Huberman 1994). The development of initial diagrams is an important first step in understanding and depicting the interaction and dynamics of the specific instance of engineering asset procurement from a CAS perspective. Wolstenholme (1992, 129) argues that the development of models which analyse system dynamics, should involve several iterations of the model. This process will be undertaken through the focus groups noted above. Homer (1996) argues that iteration is important in order to ensure the validity of the model, and that researchers should not be surprised if there are a number of stages to the development of a model process.

Homer and Oliva (2001) argue that the model of a CAS needs to be revisited on numerous occasions, in order to ensure that the model replicates reality. As Sterman (1994) argues “without modelling we might think that we are learning to think holistically, when we are actually learning to jump to conclusions”. Richardson (1996) argues that this process of checking the model with key informants of experts ensures the validity of the mental models.

Data depiction and iteration of findings from informants are thus an important part of the process of developing a qualitative model of the engineering asset management procurement from a CAS perspective.

Validity, reliability and generalisability

Validity, reliability, and generalisability are hallmarks of good research, however, these aspects can be difficult to implement in qualitative studies. Yin (2003b) outlines how validity and reliability can be enhanced in case study designs:

- Construct validity – multiple sources of evidence, have key informants review drafts
- Internal validity – pattern matching and explanation building, address rival explanations
- External validity – use replication logic in multiple case studies
- Reliability – use case study protocol, case study database
- Transferability parallels external validity in quantitative studies, and relies upon multiple cases in the one study.

As noted above, multiple sources of evidence will be used to improve the validity of constructs, and key informants will also be allowed to review summaries of interviews (Yin 2003b). By matching patterns across interviews and addressing rival explanations in the focus groups, internal validity will be strengthened (Yin 2003b). As multiple case studies will be used, replication of the same methodology and logic can improve the external validity, reliability and transferability (Yin 2003b). Thus the methodology, outlined above, by using multiple case studies, multiple sources of evidence and involving informants in checking interviews and modes, will improve the validity, reliability and generalisability of the findings (Yin 2003a).

While it may not be possible to generalise from four case studies to every other case of engineering asset procurement due to the specific nature of each system (Klein and Teisman 2007), it should be possible to generalise from the case studies back to theory (Yin 2003a). The Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM) will provide a highly useful dissemination role by virtue of access to different industry partners which comprise the Centre

Limitations

Some data is likely to be sensitive and classified – depending on the nature of the research, or may not be able to be made public. This may possibly affect the selection, although certainly the reporting, of a specific case study. However, industry partners associated with CIEAM have indicated that they would be interested in participating in the research, with some indicating that they would facilitate access to their entire supply chain. As noted in the sampling section above, the research will select across multiple asset classes in order to generate a better understanding of the various approaches to engineering asset procurement.

Assumptions

Industry partners with the CRC for Integrated Engineering Asset Management (CIEAM) have indicated interest in the project. The Department of Defence and the agency responsible for the Collins class submarines (ASC) have both expressed interest in participating. The Department of Defence is exploring CAS framework in a range of areas, including procurement. CIEAM has provided financial support to this project and will broker access to these research partners in order to facilitate access to research partners.

Cooperation by industry and government is necessary in order to gain access to interviewees and focus group participants. If cooperation is not possible for various reasons then alternative case studies from other members of CIEAM will be substituted in place of those above.

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