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# DEFINING THE DIMENSIONS OF ENGINEERING ASSET PROCUREMENT: TOWARDS AN INTEGRATED MODEL

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Procuring engineering asset management is a critical activity of all types of government, with optimal approaches to procurement still in need of identification. This paper advances a novel approach of exploring the procurement of engineering assets across a number of dimensions: Project rules, organisational interaction rules and complexity. The dimensions of project rules are held to include cost, quality and time. The dimensions of organisational interaction rules are held to be collaboration, competition and control. Complexity is seen as in the project itself, in the interaction between organisations or in the business environment. Taken together these dimensions seem salient for any type of engineering asset, and provide a useful way of conceptualising procurement arrangements of these assets.

Key words: procurement, complex adaptive systems, complexity, organisations

## 1 INTRODUCTION

Engineering assets are highly complex arrangements and their complexity is heightened by the consideration that these assets comprise both technical and social systems, are capital intensive, and typically last for significant lengths of time (often transverse generations) [1]. Engineering assets deliver critical services to the wider community, such as the generation of electricity, provision of water, and national defence [1], and the failure, neglect or sabotage of these engineering assets could result in significant adverse outcomes for society as a whole [2, 3]. 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” [1]. Engineering assets are thus significant in both economic and social terms [4].

Recognising the importance of engineering assets to society, many jurisdictions in Australia have developed policies on the strategic management of engineering assets (e.g. [5, 6] particularly in order to guide the procurement of asset management and maintenance, which is typically achieved through private firms. The peak council dealing with procurement of government assets, (or whatever) has argued that the effective and efficient management of these assets is in the best interest of government, business and society [4]. 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 [7]. 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 services from the private sector by government [8] with a focus on whole-of-life.

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 [4], the typical longevity of the assets, and the significant risk posed to society if these assets were to fail [1]. The following sections outline the challenges to identifying optimal procurement approaches, due the complexity inherent in such projects.

The paper argues that despite significant research into procurement of various types of engineering assets, optimal approaches to procurement remain to be identified. 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. The existing understanding concerning the most appropriate set of organisational arrangements for the procurement of engineering asset management will be outlined, together with what is not yet clear from the literature.

The paper concludes that perspectives from complex adaptive systems theory offer an innovative approach that should be applied to this problem. This is demonstrated by identifying the various dimensions of procurement systems – the rules which govern the system and the rules which govern interaction of organisations in the system. The paper begins by defining procurement and outlining the different types of procurement frameworks and assesses their applicability to complex engineering assets.

## 2 PROCURING ENGINEERING ASSET MANAGEMENT BY GOVERNMENT

Government has four main ways it engages with economic activity: as a regulator of industry; by redistributing taxation and spending; providing public goods and services to the public (including national defence, public safety, education, health and a range of infrastructures); and the purchasing of goods, services and assets [9]. The public procurement of goods, services and assets has a rather long history – with records of such activities dating from over millennia ago [9]. In most western democracies, the management of government services, such as engineering asset management, were 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 [10]. In the early 1990's significant changes were introduced into western democracies where those tasks which had been conducted previously in-house were contracted-out to the private sector [11]. This process of privatisation and procurement was a fundamental change in the way government went about the process of governing [12], as government moved from delivering services directly, to contracting with the private sector to deliver these services on its behalf. The process of sourcing goods and services by third parties is typically referred to by government as 'procurement'. As outlined by the [13]:

> 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.

The importance of ensuring engineering assets to achieve their intended outcomes in an effective and efficient manner, has meant that the 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, 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. [14]. [15] and [3] 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. 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 [1]. This research project explicitly seeks to address this gap in the literature by focusing on the organisational arrangements involved in the procurement of engineering assets as these inform the understanding of the key stakeholders who should be consulted when making decisions concerning critical pieces of infrastructure [16]. Such an approach looks beyond the economic and technical aspects of engineering asset procurement to the wider social, political and environmental context in which the asset is situated.

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 [8]. 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 [17]. 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 [17]. 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. [5]. 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 [17], as well as from a number of levels of government [18]. 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 [8]. Such issues are important as they relate to the efficiency and effectiveness of contractual and financial mechanisms in achieving outcomes for government.

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 [1]. 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 [10]. Procurement is in essence a series of decisions about an engineering asset which should consider a number of factors [15]. Many governments are still searching for the most appropriate way to procure engineering assets and provide an optimal system of management and maintenance [8], as well as how to govern the ongoing relationships between government and private industry [19] which are required for the effective delivery and maintenance of these assets. As will be demonstrated, 'systems thinking' provides fruitful ways of addressing the complexity inherent in procuring EAM.

## 3 OVERVIEW OF PROCUREMENT SYSTEMS

Procurement has been defined as "The amalgam of activities undertaken by a client to obtain an engineering asset" [20]. This paper examines these activities from a systems perspective. Systems perspectives on procurement are not new, with authors first suggesting such an approach in the early 1990s [20, 21]. For example [22] argues that buildings are procured through organisational systems. "In particular the concept of an open system has become a popular model with which to conceptualize a construction firm or project which interacts with the environment in which it operates" [23]. Such approaches are derived from early systems studies, and clearly focuses on procurement of engineering assets as a socio-technical system with its emphasis on the organisational arrangements involved in the procurement of EAM. The following definition of procurement provided by Masterman [2] has been expanded from one focussing on the design and delivery stage of construction assets, to apply to all engineering assets and the whole life cycle of an asset:

> A procurement system is the organizational structure adopted by the client for the management of the design, delivery and maintenance of an engineering asset [Adapted from 20]

The procurement literature devotes considerable attention to various types of organisations, which are outlined in detail below.

### 3.1 Organisational systems in procurement.

The first point to note with many procurement organisational systems, is that these arrangements are typically temporary project based organisations [24], with elements of the temporary organisation drawn various sections of other more or less permanent organisations. Consequently, there is general agreement in the literature that project based organisations are "inter-firm networks of independent organisations which come together on a temporary basis to achieve a specific end" [25, 330]. For example, Cherns and Bryant [26] argue that construction projects are in effect temporary multi-organisations:

1. A construction project is an engagement over different points in time of several organizations – consultants, contractors, subcontractors and suppliers – with a client system that is itself organizationally complex
2. The management of a construction project from inception to completion is a function of a temporary multi-organization comprising several parts of these component organizations
3. The TMO is a device for handling uncertainty, the structure and mode of functioning of which will depend on the nature of the uncertainties and will change over time as the focus of uncertainty shifts during the course of the project [26]

### 3.2 A way to determine the best procurement method is needed

Thus, despite the significant amount of work undertaken to date, finding a way to determine the best procurement system for a given situation remains to be found. No one predictive tool has been able to predict with absolute certainty the 'best' procurement approach for a given situation [8]. As [27] notes "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". Clearly there is a gap in the literature on identifying the most appropriate procurement approach which can take into account the sheer number of variables involved in government procurement arrangements. Some authors argue it is a little more than a gap:

> Such debate of whether a universal set of criteria for procurement method selection can be established seems to be an endless issue which becomes a black hole to attract researchers on procurement system development [28, 612].

Organisations respond to complexity either through attempting to reduce complexity by understanding and responding to it in a codified manner, or by creating a range of possible responses [29]. The search for optimal procurement arrangements which apply in every given context appears unlikely to be achieved, given the complexity of the number of elements involved.

Thus a way needs to be found to cope with the sheer number of factors which are held to affect the outcome of procurement, the suitability of the project is dependant upon the interaction between complexity in the environment, the task, technology and organisational structure [23], not to mention policy settings, skills and goals of clients and construction firms. While much work has been undertaken examining the relative merits of specific detailed procurement arrangements, this paper takes a different approach – to use complexity theory to explore and better understand the various dimensions in procurement arrangements.

### 3.3 A way forward – using complex adaptive systems theory to explore the complexity of procurement

Complexity theory is postulated to be a key and productive way of exploring procurement – although specific operationalisation of the theory in procurement contexts remains to be undertaken. Bovaird [30] argues that CAS theory is a useful theoretical perspective to understand procurement as it provides a framework for examining the relationships of organisations in a system, together with the rules they utilised to make decisions. As noted above, numerous authors have already argued that the organisational arrangements of procurement could be understood of as an open system [23], although application of complex adaptive systems theory is quite new.

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 [31]. [32] contends that rules can be classified into two main types – rules which regulate the action of organisations, and rules about the system itself. This point is echoed by Klijn [33, 34] suggesting that in public policy systems there are rules which focus on the system, and those which relate to the interaction of organisations.

The notion of organizational decision making based upon rules is not totally new to public management, as March and Simon have argued [35]:

> 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.

For this paper, system rules are those which relate to the project overall, and interaction rules are those which govern the relationships between organisations in the procurement system. Procurement system rules are discussed initially below.

### 3.4 Project procurement rules:

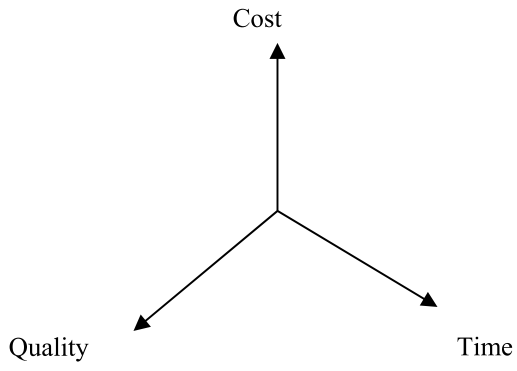
One of the critical reasons why projects are seen to fail is a lack of agreed to measures to assess the success of projects [36]. Cost, quality and time are often the benchmarks used by Government auditing authorities in their assessment of the effectiveness of a given project [37]. According to Ive and Chang [38] clients have to make a choice between the 'inconsistent trinity' of client goals (cost, quality and time) in each procurement case. From a CAS perspective, these rules form competing hypotheses [32], and organisations must chose between them. A brief overview of these rules, which are well known in project management, is provided below.

**Cost:** Traditionally cost was seen as meaning the up front costs of a particular asset – where as more recent treatments have argued that the life cycle costs of assets are the true costs of the asset [39]. Lower up front costs, may relate to higher overall costs as poorer quality materials have to be replaced more often. Consequently, the adoption of whole of life costs is a different measure to up front costs – a different rule which may well result in a different product.

**Quality:** Quality can be perceived as either compliance with technical standards, functionality or aesthetics; [20]. Quality is typically determined by the client.

**Time:** Time is a relatively uncomplicated assessment of the chronological time required to complete a project. Some forms of project organisation, by their design, are more able to deliver project quicker than others, due to the overlapping of various stages of the delivery process.

**Figure 8 – Dimensions of Procurement Rules**



Having reviewed project system rules, the rules for interaction between organisations involved in procurement, which are far less prominent in procurement literature, are discussed below.

### 3.5 Interaction rules

As noted above, procurement is in essence an organisational structure put in place by a client in order to effect the planning and delivery of a specific asset. There are numerous examples of different types of organisational arrangements [See 20, 40 for an overview]. For organisational theorists, there are three main types of organisations: markets, hierarchies and networks. Keast, Mandell and Brown [41] note that these are pure or archetypes and in realty a mix of the three modes of governance is typical in a given set of arrangements. Provan and Lenis [42] also note that there are a variety of forms of networks possible in government service delivery. Table 1 provides a useful summary of different organisational forms and their underpinning logics.

Figure 9– Summary of organisational forms and client objectives [Adapted from 41]

| **Relationship to Organisational Archetypes** | **Core dimension** | **Concept of working** | **Objective** | **Logic** | **Drawback** |
|---|---|---|---|---|---|
| Market | Competition | Working against | Best cost | Competition keeps price down | In markets where competition is weak – leads to opportunistic behaviour |
| Network | Collaboration | Working with | Best relationships | Collaboration reduces conflict / realises complex project | In situations with low complexity – not worth the establishment costs |
| Hierarchy | Control | Working for | Best quality, certainty | Control ensures quality | Where outcomes are difficult to specify and therefore measure – control difficult to ensure |

For this paper, the most important aspect of this is not the title of the organisational form, but its core dimension, the underpinning logic and how this aspect affects inter-organisational relationships.

These three core processes identified in the organisational literature are pertinent to the study of project based organisations as well – the dimensions, as we are terming them, of competition, collaboration, and control.

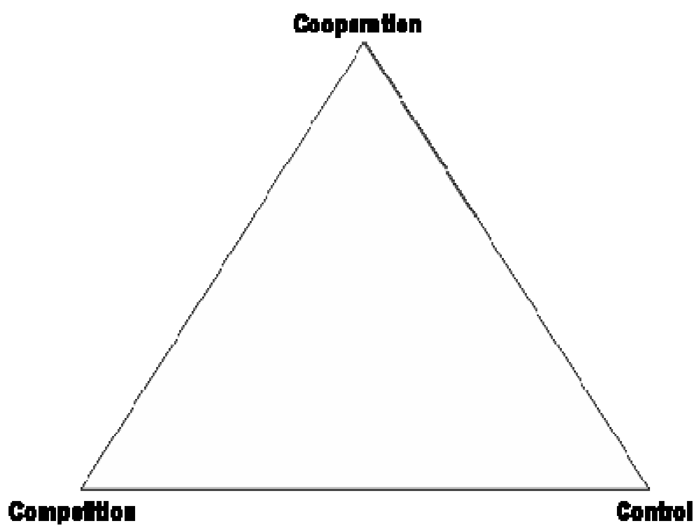



**Figure 10- Dimensions of project governance mechanisms**

Following Keast et al. [41] we argue that no individual procurement system follows a pure form of these, but rather there is a mix of these dimensions of governance in any given project, and how managing these dimensions determines the appropriate form of project governance.

Rather than seeking to find idealised forms of networks, markets or hierarchies, this paper argues that the central logic of the governance form is what matters – particularly the dimensions of competition, collaboration and control, as these influence the manner in which organisations in the procurement system interact. These dimensions are discussed further below.

**Competition – working against**: Markets rely on competition (typically through competitive tendering) and legal contracts to moderate interactions between organisations [41]. Competitive tendering seeks to minimise costs by pressuring contractors to lower their prices. This has been the main mode of procurement, particularly in infrastructure projects [20]. Even if highly collaborative approaches to organisational arrangements are eventually undertaken, this does not mean that competition is completely absent from the procurement system. Competitive tendering, competition within firms, together with competing policy objectives, technologies and ideas are all possible within a collaborative project, as well as a competitive approach. The point here is not the presence or absence of competition, but rather how competition is managed in the procurement process.

Recently more cooperative approaches to procurement have been explored, which engaged contractors earlier in the procurement process.

**Collaboration – working with:** There are two main forms of construction relationships, which are determined by the client in the manner in which they procure construction services: low trust competitive route, and high trust cooperative route [43]. Cooperation and trust is difficult to achieve between firms involved in procurement, even though this is held to be beneficial [44, 45]. A challenge for clients procuring engineering assets is to find the right balance between competition and cooperation [Teece 1992, cited in 46].

**Figure 11 – Competition and Cooperation in Procurement phases (based on Eriksson [46])**

| Procurement stage | Issues related to competition | Issues related to cooperation |
|---|---|---|
| Specification | By the supplier or client | Joint specification with shared responsibilities |
| Bid Invitation | Open bid procedure | Direct negotiation |
| Bid evaluation | High weight on price | High weight on soft parameters |
| Contract formalisation | Formal, comprehensive | Informal, incomplete, coupled with relational norms |
| Compensation | Fixed price | Including incentives |
| Collaborative tools | Low extent | High extent |
| Performance evaluation | By the client | By the supplier |

Eriksson [46] found that while cooperative based approaches to procurement where understood as important and desirable by clients, they did not understand how procurement affected cooperative and competitive behaviour. What we are advancing here is a framework for explicitly addressing these issues in the design of the procurement system itself.

**Control – working for:** Hierarchies seek to regulate behaviour through various overt control mechanisms [41]. The notion of control in the procurement literature is somewhat lacking, possibly because the view is of autonomous organisations working together. For government procurement, the issue of accountability is very salient as governments agencies are accountable to their ministers, to parliament and ultimately to the public for the outcomes of procurement processes. Like competition and collaboration, the issue is not about the present or absence of control, but how control is achieved in the procurement system. Quite often control is demonstrated in the form of contract, with alliance type contracts having lower levels of control, than say fixed price contracts.

Having briefly reviewed procurement system rules, and organisational interaction rules, the relationship between these two rules is explored in the next section.

### 3.6 Relationship between project rules and interaction rules

There is a relationship between the organisational arrangements (interaction rules) and the goals of the project (what we have termed procurement system rules). Indeed, the incorrect organisational arrangement can negatively impact cost, time and quality criteria [8]. For example, if time is of the essence, then using a market based sequential tendering method for all phases of the construction process (design, construction, maintenance) would be inappropriate [20], as significant time is lost in the call, and assessment of tenders at each stage of the process. Likewise if cost is the prime concern, then collaborative approaches, which engaged multiple stakeholders in the design decision will not lead to price certainty or final costs of the project, as decision making on the final design is distributed. The optimal organisational arrangements “depends on the goals and requirements set for functionality, cost, time and quality” [8, 689].Therefore the strategy must be to align the procurement system with types of projects. The following diagram summarises the relationship between project type and client objectives.

**Figure 12 - Organisational form and its relationship to client goals [Adapted from 47]**

| Goals | Competitive (Market) | Control (Hierarchy) | Collaboration (Network) |
|---|---|---|---|
| Speed | L | H | H |
| Cost | M | L | H |
| Incorporate variations | H | L | H |
| Cost certainty | M | M | L |
| Client involvement | L | M | H |

H=High, M=Medium, L=Low

### 3.7 Dimensions of engineering asset procurement

Combining these two sets of rules, then, a set of project procurement dimensions can be advanced. As outlined above, the competing rules of cost, quality and time, are affected by the rules which govern the interaction between organisations involved in the procurement system. Some organisational arrangements are better suited to meeting specific organisational goals than others. Figure 4, provides a more visual representation of this.

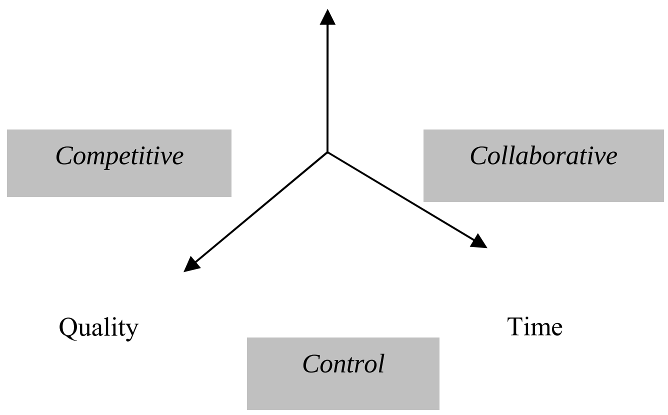



**Figure 13 - Relationship between dimensions of project governance and project rules [based on 48]**

## 4 COMPLEXITY IN PROCURMENT

EAM projects can be seen as being complex in a variety of ways: complexity of the project itself (technological complexity), complexity in the project relationships (relational complexity) and complexity in the business environment around the project (Business environment complexity) [23]. These are discussed below.

### 4.1 Project (technical) complexity and procurement

Loch et al. [49] argue that complexity can roughly be estimated as the sum of all project elements times the sum of all task and relational interactions. In this sense, the number of interacting parts determines the complexity of the asset. Perrow [50] follows this approach in assessing the complexity of various types of assets and organisations – with manufacturing seen as fairly simple and loosely coupled industry, where as military organisations are seen as highly complex, and tightly coupled. The complexity of asset and the way this complexity is handled can have the most critical influences on the formation , development and subsequent performance of the temporary construction organisation [26].

Katsanis,Cahill and Davidson [51] provide a very useful summary of the typical complexity of building projects:

> A building requires the cooperation and coordination of an inordinate number of professional disciplines and trades for its construction… a dozen professional disciplines, such as architecture, civil, structural, mechanical and electrical engineering, as well as other specialities, and at least forty to sixty different trades supported by an even larger number of suppliers of materials and equipment providing a wide range of products, the number of which is counted in thousands. Added to these is the fact that most buildings are unique; as a consequence the product is a prototype …

In their study of the relationship between technological uncertainty and network structure Rosenkopf and Schilling [52] found that the more uncertain the technology the greater the number of relationships formed by firms. Generally, the more complex a project the more likely a collaborative approach to the project [53]. Consequently,

Turner and Simister [54] argue that alliances are ideally suited for highly complex engineering assets. Conversely, they would not be suitable to projects which are simple, given the intense investment needed in building trust and relationships at the start of the project.

Winch [25] advanced a series of propositions concerning the most appropriate governance form for project organisations based on the nature of uncertainty, asset specificity and uncertainty. On projects with high levels of project uncertainty – emphasis on effectiveness and flexibility, whereas on projects with low levels of uncertainty (high certainty) – the emphasis can be on efficiency.

Winch [25] does not test these propositions, and his framework appears to contain an error. Winch [25, 333] argues that "asset specificities occur when, due to the small number of players, a fully competitive market does not operate". Vining and Globerman [55] term this type of situation one of low contestablity. Asset specificity has to do with how time, place, performance specific an asset is [55]. For example, most buildings have a higher degree of asset specificity (one of kind), than other types of engineering asset. In contrast, cars, tanks and busses have a lower level of specificity as they are mass produced, and are mobile. Unfortunately, this misunderstanding renders most of Winch's [25] models and conclusions moot, although calling for further research on the governance of project based organisations.

**Figure 14 – Impact of client/contractor relationship and complexity of asset on Procurement system choice [54]**.

| | | **Business Challenge** | |
|---|---|---|---|
| | | Simple | Complex |
| **Business Culture** | Trust and Mutual respect | Relational contracts<br>High definition<br>Target sum bidding<br>Focus on efficiency | Alliances<br>Goal alignment<br>Early involvement<br>Focus on effectiveness |
| | Transaction based | Conventional<br>High Definition<br>Lump sum<br>Claim mentality | Get out |

Despite Turner and Simister's [54] argument that a situation in which complex projects need to be delivered when relationships with industry are transaction (competition) based, it appears highly probable that governments face such situations, and have no capacity to 'get out' as they need to deliver the asset as part of their obligations to society. Consequently, while more collaborative approaches to procurement arrangements may

Thus the more complex an asset being designed and delivered, the more collaborative the approaches are needed to the project. Conversely, a simple project would suggest a less complex organisational form.

### 4.2 Relational complexity and procurement

The number of organisations involved in an EAM project promotes a high level of interdependence at a project level, thereby increasing the relational complexity of these projects [56]. Price [57] makes a distinction between complicatedness and complexity, arguing that: "complicatedness is an emergent property of complexity in organisations". In reviewing the literature, Price also distinguished between the various uses of complexity applied to organisations: complexity as an umbrella term to examine organisations from a systemic perspective; complexity as a way to understand systems which operate far from equilibrium, and finally as a way to examine intricate forms of inter-organisational relationships that go beyond simple notions of market and firm. It is this latter form which is being referred to here.

Government is a special case in relation to procurement of engineering assets. Much of the procurement literature treats government as a simple entity – almost ubiquitously referred to government as the 'client'. Government can in fact 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" [58]. 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 [59]. Further complexity emerges as multiple departments may become involved in the planning and delivery stages of a project either directly [60], 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 [61] or occupational health and safety [59].

The organisational arrangements of procurement systems can also be assessed in terms of their complexity, as set out in Table 8.

**Figure 15 - Complexity of organisational structures (adapted from Boisot and Child [29]**

| Type of structure | Relational complexity | Cognitive complexity | Overall Complexity |
|---|---|---|---|
| Competitive (markets) | High | Low | Medium |
| Control (Hierarchies) | Low | Low | Low |
| Collaboration (Networks) | Medium | High | Medium - High |

Hence the suggestion that simple projects be handled through market forms of organisation makes sense. However the use of alliance types of organisation (based on shared values and goals) is far better for more complex type of project. What Boisot and Child [29] help to make clear is that organisational arrangements are not just responses to complexity, but can also contribute to the complexity of a given project.

### 4.3 Business Environment Complexity

Masterman [20] argues that the various procurement systems were not totally dependant upon the nature of the project, but rather were the result of a range of factors in the business environment itself. The period following WWII, was a time of rapid economic expansion for western nations with high demand for buildings and the need for rapid completion of construction at minimum costs [20]. The 1970s were a period of recession due to the oil crisis, with an increase use of the managed approach to procurement. Numerous reports were carried out which criticised the time and costs associated with many building projects, part of which were due to the oil crisis. It was also held to be a period of experimentation in a range of procurement systems due to escalating costs, increasing complexity in building designs and the size of projects, and increasing demands of clients [20]. From 1980 to the current time, frustration over the length of time taken to finalise construction project has led to increased use of the design-build procurement system. Masterman [20] noted however, that such changes were only after considerable resistance to new forms of organisation where over come.

In fact some authors argue that complexity determines the most appropriate organisational form for a given project. Some procurement texts simply refer to complexity in the environment, when what is intended is complexity in the business environment, rather than the ecological situation of the asset. The distinction between business environment and ecological environment of a building is maintained here for clarity:

> In relatively stable environments, have a centralised structure makes sense as it favours the exploitation of existing resources to achieve maximum profit; but in today's rapidly changing environment, driven by high rates of change, a more adaptive form of organisation enhances the long term sustainability of the firm [62].

**Figure 16 – Classification of Construction Environment [23]**

| | |
|---|---|
| Cell1 : Low perceived uncertainty<br><br>1. Small number of factors and components in the environment<br>2. Factors and components are somewhat similar to each other<br>3. Factors and components remain basically the same and are not changing | Cell2 : Moderately low perceived uncertainty<br><br>1. Large number of factors and components in the environment<br>2. Factors and components are not similar to one another<br>3. Factors and components remain basically the same |
| Cell3 : Moderately high perceived uncertainty<br><br>1. Small number of factors and components in the environment<br>2. Factors and components are somewhat similar to one another<br>3. Factors and components of the environment are in a continual process of change | Cell4 : High perceived uncertainty<br><br>1. Large numbers of factors and components in the environment<br>2. Factors and components are not similar to one another<br>3. Factors and components of environment are in a continual process of change |

Thus the procuring of engineering assets can involve complexity in a number of ways: the technical complexity of the project itself, relational complexity in the delivery organisations, and complexity in the business environment.

In a dynamic environment the structure is more fluid as the "organisation cannot predict future activities and cannot rely on standardisation or formalisation as a coordinating mechanism but must seek mutual adjustment and encourage informal communication" [23]. Likewise in a complex environment, the ability to understand the situation, gain access and make sense of information is difficult, hence the "decisions are decentralised to prevent the effects of over loading" [23]. More complex environments and more complex the technical system being implemented, the more decentralised the structure involved in the delivery of the construction [23].

### 4.4 Summary of Complexity in Procurement

The more complex the contracted service – and the greater the significance of failure, the more likely that a collaborative approach to organisation (eg alliance and partnering) [53].

Thus a conceptual model of the relationship between these factors is advanced below:

As with other dimensions identified in the literature it is possible to portray the project complexity as not one type or an other, but along a number of different axes .

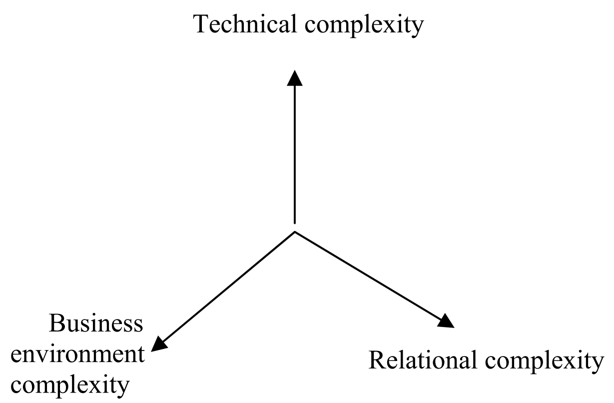



**Figure 17 – Dimensions of complexity in EAM procurement**

Thus, in exploring the dimensions of project complexity, it is possible for a project to be technically quite simple, and yet operate in a highly complex business environment of high, and one of medium relational complexity. Such an approach provides a more robust approach to conceptualising complexity, which assists in developing effective responses to complexity. It should be possible to develop an aggregate score of the complexity of the procurement project, as a simple method of adding up the relative dimensions of complexity.

### 4.5 Summary

Much of the existing literature on procurement holds that there are three elements which inform a client's procurement selection processes: the objectives of the client (time / cost / quality), the project characteristics (eg. Complexity) and the external business environment (eg labour market) Luu, Ng and Chen [63].

> One way of viewing the task of the most appropriate organisational form for a construction project is to undertake this task from a contingency perspective – on the understanding that there is no one best way to organise a project, but 'suitability' involves a complex interaction between the environment, the task, technology and organisational structure [23].

The goal of this paper has been to set out the dimensions of these interaction, particularly the rules for the system, the rules for how organisations interact, and the interface between these and the various forms of complexity involved in engineering asset procurement.

The first set of dimensions are the rules concerning the project itself, which we have argued consist of time, quality and cost. The second dimension is that of the rules which govern the interaction between organisations. These governance modes of competition, collaboration and control can also affect project outcomes. The final dimension examines the extent of complexity in the asset itself, complexity in the organisational governance arrangements, and complexity in the business environment surrounding the project.

These dimensions provide a useful framework for examining procurement arrangements as they allow for exploration of organisational arrangements. Further these dynamic frameworks move the focus of analysis from attempting to find ideal matches of specific procurement arrangements to specific projects, and instead focuses on identifying the dimensions relevant to all procurement situations. From a contingency perspective there is no one ideal way to procure assets. Instead, the dimensions advanced in this paper provide a way of conceptualising the procurement of engineering assets, and therefore improving our understanding of procurement processes. Improved understanding should lead to improved practice in the procurement of engineering assets.

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