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Robust Decision Making for Agile Systems Development Part 1: Exploring the Paradigm

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Abstract

The need for agility in operational systems within the defence enterprise and procurement domains has been identified by many authors, and over time, there have been a number of initiatives and programmes that have sought to identify the nature of agility, and the means by which it can be defined and employed within individual cases and scenarios. These have identified impediments to the successful realization of agile practices and methods, particularly the resilience of agile decision making throughout the conceptual understanding, design and implementation of the operational system. To further investigate the extent to which this process can be implemented in a robust and reliable manner, Cranfield University created the 'Robust Enterprise-based Approach for Agility in Capability Through-life (REA^{2}CT)' framework, which provides a number of functional steps to institute a systems development lifecycle approach to producing agile solutions for use in networked systems and systems-of-systems. This paper briefly examines the Customer Need (CN) for the enterprise-based delivery of system (of systems) agility into the operational domain. Axiomatic Design (AD) theory is used to describe the REA^{2}CT framework, identifying Functional Requirements (FRs) which might satisfy the CN for agility. Initial Design Parameters (DPs) are proposed to satisfy the FRs

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1. Introduction

The need for agility within procurement and operational systems (and system-of-systems) has been identified by a number of authors [1 – 3], and this need is especially evident within the defence sector [4 – 5]. There have been many attempts to identify the nature of agility [1, 6, 7], and the impediments to its implementation [1, 2, 7]. Among the most significant issues to face an organization in the successful introduction of agility are:

- Determining the Agility requirement [7]
- Instituting an architecture to facilitate agility [8]
- Identifying Enterprise/Strategic-level impediments [2]
- Achieving the requisite level of organizational flexibility [1]
- Reacting to uncertainty [9]
- Instituting the ability to reconfigure existing assets to meet a rapidly changing need [7, 9]

In response, there have been a number of attempts within defence sector, industry and academia to address the situation. Examples of this are JSP-777 [4] and the joint industry-UK research council-funded Network Enabled Capability Through Innovative Systems Engineering (NECTISE) research programme [10]. Following on from this research, and in a bid to understand how the defence organization can meet the imperative for operational agility, Cranfield University developed the REA^{2}CT (Robust Enterprise-based Approach to Agility in Capability Through-life) framework [9, 11].

Having developed the REA^{2}CT framework, a need can be identified to test its viability – although the framework was generally well received upon its presentation [11], there is a need to examine how well the requirements of organizational and operational agility are met, to ascertain the extent to which modifications to the framework might be needed to facilitate its use.

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To this end, it is proposed to apply the Axiomatic Design (AD) theory developed by Suh [12, 13] to explore how well the design parameters embodied within the framework meet its requirements. AD theory identifies four 'domains' which must be considered. These are depicted in figure 1.

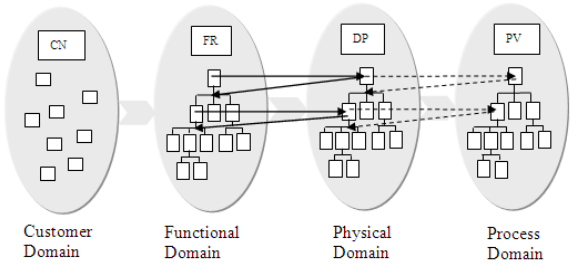

Fig 1. Domains of Axiomatic Design [14]

From figure 1, it can be seen that Customer Needs (CNs) are first identified, from which Functional Requirements (FRs) are then derived. Design Parameters (DPs) are then, in turn, derived from the FRs. The analysis of the REA^{2}CT framework needs to consider if its requirements (FRs) are clearly derived from the CNs for agility, and then the extent to which Design Parameters (DPs) can be derived and instituted to successfully allow independent satisfaction of FRs whilst keeping complexity within the design process to a minimum.

This paper will concentrate on the CN-FR derivation. The nature of agility will be briefly examined, as will the problems facing its achievement, to demonstrate what the requirements for an organization's response to the need for operational system (of systems) agility might be. The nature of the REA^{2}CT framework will then be described to illustrate its key stages. An initial set of FRs and DPs will be proposed. The detailed AD analysis of the FR-DP is the subject of a second paper, and this is described in the results and conclusions section.

2. The Nature of Agility

There are many definitions of agility, and an accompanying number of observations of what is required to successfully institute it. The Oxford Dictionary [15] defines agility as:

"Ability to move quickly and easily", and

"Ability to think and understand quickly"

This idea gives the notion of having to comprehend and then react rapidly to a situation. The ability to move quickly and easily might be seen to depend upon pre-requisites which facilitate that movement (or action). This notion is reinforced by definition from Mackley et al [7], which states:

"Agility is the ability to respond to changing circumstances where:

- Ability is characterized by readiness and speed of action
- Response is:
  - Making use of an existing configuration (by internal means)
  - By reconfiguration (facilitated by external means)
- Changing circumstances may be:
  - A change in objective
  - A change in environment
  - A change in condition
- Agility is measured by:
  - Speed of action
  - Cost in resource
  - Impact on effectiveness"

Other definitions suggest agility to be a "response to the nature of the modern operating environment", which is "increasingly dynamic and complex, and… [contains] inherent uncertainty" [6], "a response to the challenges that a company faces" [2], and "a business-wide capability that embraces organisational structures, information systems, logistics processes and, in particular, mind-sets" [16].

These definitions, typical of others in the field, suggest that there are two facets of agility that need to be considered: the ability of the organisation to gear up for the provision of an initial, bounded operational agility, and subsequently, the organisation's ability to respond rapidly to a change in need or requirement, dictated by an unpredictable, or unprecedented operational event. From this point of view, the customer needs (CNs) for an organisation to be capable of facilitating operational agility might be seen as follows:

[Initial CNs]

1 Identification of the rapidity and nature of response required
2 Develop organizational systems/services to facilitate creation of an operational architecture that promotes agility
3 Create initial architecture of configuration(s) to facilitate agile decision making
4 Define/validate potential operational scenarios/configurations

[Subsequent CNs]

5 Choose appropriate configuration to suite operational need
6 Ability to respond to requirement change rapidly

Broadly, these CNs can be seen to map to the issues identified earlier. Having identified needs for facilitating operational agility, the REA^{2}CT framework will now be examined to identify functional requirements (FRs).

3. REA^{2}CT framework

Agility is one of the key themes identified as being necessary to the provision of operational capability [17, 18]. This was reinforced by Henshaw et al [10] in their discussion of necessary themes to facilitate Network Enabled Capability, a programme intended to achieve "the enhancement, or realization, of… capability" [10]. This is demonstrated by

figure 2, which places agility at the heart of facilitating operational capability.

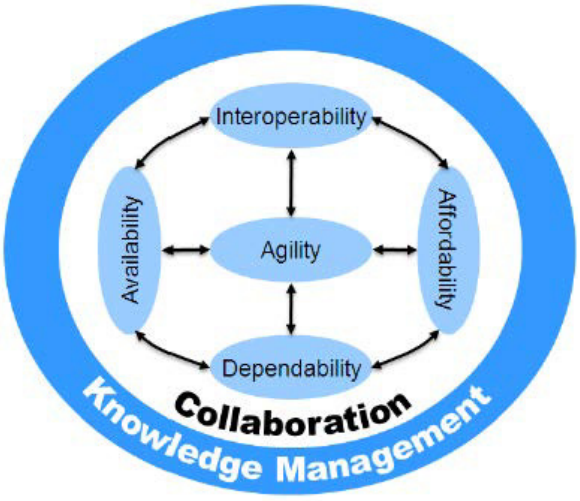

Fig 2. Themes required for facilitation of NEC/Operational Capability [10]

3.1. Identifying the Required Level of Agility

When agility is considered, it can be postulated that a necessary activity is to understand the nature of that agility, and the rapidity with which it is required: unless the agility requirement is understood, means cannot be put in place to achieve it. To this end, Mackley [19] suggested a four-level classification of agility, which is reproduced at table 1.

Table 1. Characterizing levels of agility

Level of agility	Relevant Military/Acquisition Concept	Measure
Level 1	Tactical operations/ support	Minutes to hours
Level 2	Operational operations/ support	Days to weeks
Level 3	Strategic operations/ UOR	Months to a year
Level 4	Capability management /Lifecycle management	Years

Furthermore, it was recognized by Mackley et al [7] amongst others that there are two elements that need to be considered if agility is to be achieved. These are:

- How… operations are conducted in real-time, and
- What preparation is required to achieve [agility]

These elements satisfy CN 1 and suggest that it is not just the need to facilitate operational agility rapidly in the face of changing requirements that must be considered, but also the fact that enablers to enact that facilitation must first be developed. This in turn introduces the requirement to consider all of the procurement lifecycle stages [11]. Operational agility takes place within the in-service stage of the lifecycle, but enablers to facilitate it must be considered at concept stage, and developed during the implementation/build stage of the lifecycle. Thus enterprise-level thinking must be considered, encompassing the procuring organization, contracting organizations, operational space, and potentially political and other influences. An Enterprise Architecture-based approach must therefore be adopted to facilitate agility [7].

If this wider thinking is adopted, the functional requirement (FR) to determine the required level of effect or agility can be considered to satisfy CN 1 as stated above. REA^{2}CT facilitates this through a 'time dependency matrix' design parameter (DP), in which the levels of agility described in table 1 can be mapped to agility enablers such as training, infrastructure, information provision, logistics etc. From this can be seen which activities can be accomplished in a rapid, hence agile, timeframe, and which need to be considered in a longer timescale, thus potentially reducing the ability to be agile. This process of dependency analysis is explored more in Mackley et al [9].

3.2. The Need to Reconfigure the System

Having analyzed dependencies that might affect agility, it is now necessary to consider what level of systems reconfiguration is required. For a new procurement, CNs 2 and 3 may be satisfied by an understanding of the number of operational configurations required to meet scenarios suggested by operational analysis, but equally possibly, the system under consideration may already exist, in which case the need could be seen to be the need to reconfigure the existing system architecture to meet new and possibly unprecedented operational threats. In the latter case, the CN 5, and 6 for potentially rapid reconfiguration means that activities associated with development may require to be performed in demanding operational timescales. Therefore the nature of the required reconfiguration(s) must be identified, and compared against the agility dependency analysis outlined in the previous section. FRs to define services and architect them within suitable configurations must exist to satisfy this need. The boundary of the problem can then be identified, allowing comparison of the required operational agility against the current enterprise agility.

3.3. Assessing the Enterprise Agility Profile

Having gauged the nature of the required reconfiguration and the activities necessary to achieve it, the next stage is to assess whether the enterprise can facilitate this need. Currently, urgent "reconfiguration" activities are performed through fast-track procurement programmes such as the UK Ministry of Defence's Urgent Operational Requirements (UORs) [20]. The extent to which this existing structure can support the reconfiguration requirement must now be examined. Figure 3 illustrates normal timescales for procurement against the operational agility timescales.

Fig 3. Operational and enterprise agility timelines [11]

It is essential that the current Enterprise Agility Profile (EAP) be assessed to demonstrate that it proves sufficient to deliver the required operational agility, and therefore satisfy CNs 4 and 5. Where this is not the case, CN 6 for a more rapid or agile process (i.e. a UOR-type activity needs to be accomplished in weeks rather than months as shown in figure 3), or at least more agile activities, is required.

3.4. Confirm the Operational Agility Level

Having understood the demands placed upon the enterprise by the reconfiguration need, the next step is to satisfy CN 4 and validate that the (revised) Enterprise Agility Profile (EAP) can deliver configurations of services to meet the operational need, and that all dependencies identified during the dependency analysis have been considered and accounted for. An FR to satisfy this by choosing and deploying the appropriate configuration must therefore exist. This should confirm the nature of the required operational agility level, and that it can be achieved, then allowing consideration to be given to the wider System of System process.

3.5. System of System (SoS) Process

The enterprise, taking into consideration procuring organization(s), inhabitants of the operational domain/space, and any other relevant parties, may be seen as a system of systems. The interoperability between these elements must therefore be modelled to ensure that delivery of agility into the operational domain/space is rapid, cohesive, and holistic in nature. This will ensure that CN 2 is addressed.

The amount of effort and activity depends upon the Enterprise Activity Profile (EAP), and the degree to which it must change to ensure that the required Operational Agility Level is met. It is important to understand the impact of this, as the amount of change necessarily takes time, and thus affects the ability to be agile.

Moreover, the Systems of Systems process needs to be based on premise of the "V" lifecycle that validation is required against the identified need. The need for reconfiguration – involving integration activities and potentially detailed design – will therefore ultimately determine the agility achievable.

3.6. Lifecycle Management and Industry

Industry needs to review its Life Cycle Management processes in the light of the need for operational systems agility [11]. Fundamental change is not necessary, as the constituent systems of agile mission groups still need to be developed and this will require familiar development lifecycles. Instead, operational agility requires the addition of "Systems of Systems Engineering (SOSE)" which is the ability to engineer/re-engineer the system-of-systems at both an elemental and holistic level to react to any new or revised operational circumstance. This (SOSE) allows CNs 5 and 6 to be satisfied through FRs which define potential configurations, and reconfigure them when faced with unanticipated operational circumstances. The SOSE process, described John et al [21] consists of an early concept phase, and a process that responds to operational needs. The process shows that normal development activities will occur during the System of Systems Concept phase, but that a rapid System of Systems Engineering stage is required in operational timescales to facilitate agile reconfiguration in the face of potentially unprecedented threats or events. This will necessitate agreements with industry, depending on the required operational agility level and Enterprise Agility Profile (EAP), and will require the use of agile methods and techniques.

3.7. Summary of the REA^{2}CT Framework

The REA^{2}CT Framework is a means to facilitate understanding of the operational agility need, and meet the CNs set out earlier by modelling and instituting an enterprise-wide structure to address the means to deliver agile system-of-systems reconfiguration into the operational domain. The FRs for REA^{2}CT, discussed in preceding sections, satisfy the CNs by scoping the requirement for an enterprise-based as set out overleaf in table 2. It is also possible to suggest initial design parameters (DPs), based upon the stages of REA^{2}CT as outlined above, and these are described in table 3.

These have been abbreviated slightly from those stated earlier to enable ease of description. FR3, "Create Service Oriented Architecture", reflects the customer need (CN) to identify institute an architecture that describes a collection of services that can be configured in a manner(s) that will address given threat situation(s).

DP 1, "Time Dependency Matrix", refers to the creation of a mapping which describes the required effects (FR 1) and the level of agility (described in table 1) with which it can be achieved. Hence the amount of time taken for each element of the required effect to be achieved can be gauged, and the overall time dependency – dictating the possible agility profile – can be ascertained.

Table 2. Mapping of Customer Needs to Initial Functional Requirements of the REA^{2}CT Framework

Customer Needs (CN)	Functional Requirements (FR)
1. Identification of the rapidity and nature of response required	1. Identify Effect/Need
2. Develop organizational systems/services to facilitate creation of an operational architecture that promotes agility	2. Define required services
3. Create initial architecture of configuration(s) to facilitate agile decision making	3. Create Service Oriented Architecture (SoA)
4. Define/validate potential operational scenarios/configurations	4. Identify and define possible configurations
5. Choose appropriate configuration to suite operational need	5. Choose/Deploy appropriate configuration
6. Ability to respond to requirement change rapidly	6. Reconfigure

Table 3. Initial Functional Requirements for delivery of Operational Systems Agility, and Design Parameters of the REA^{2}CT Framework

Functional Requirements (FR)	Design Parameters (DP)
1. Identify Effect/Need	1. Time Dependency Matrix
2. Define required services	2. Reconfiguration activities
3. Create Service Oriented Architecture (SoA)	3. Enterprise Agility Profile
4. Identify and define possible configurations	4. Operational Agility Level
5. Choose/Deploy appropriate configuration	5. System-of-Systems (SoS) process
6. Reconfigure	6. Lifecycle Management Process

4. Results and conclusions

This paper has briefly described the nature of agility, along with some of the issues facing the facilitation of operational systems agility. The analysis has identified CNs for agility, and explored what the functional requirements (FRs) for an organization's response to the need for operational system-of-systems agility might be. A framework for the meeting of these requirements has been described. The agility (FRs), along with the key stages (or design parameters, DPs) of the REA^{2}CT Framework are summarized in table 3.

Having described the REA^{2}CT Framework, it is necessary to analyze it to ensure that requirements identified earlier in table 3 can be satisfied independently of each other. The technique chosen for this analysis was Axiomatic Design [12, 13], based upon the author's previous experience in using the technique to determine the independence of requirements in complex systems design [22], and to explore the design decomposition of large engineering systems [14]. Using Axiomatic Design (AD) theory, an initial Design Matrix (DM) can be defined to show the extent to which FRs can be satisfied independently by the DPs. The initial DM for REA^{2}CT is shown in figure 4:

FR\DP	1	2	3	4	5	6
1	X					X
2	X				X	
3	X	X	X		X	X
4	X			X	X	X
5	X				X	X
6						X

Fig 4. Initial Design Matrix for REA^{2}CT

This initial configuration suggests a coupled design [13], and therefore must be examined in greater depth to ensure independence of FRs and to reduce the complexity of the FR-DP relationship as much as possible. This application of AD theory is described in Barker and Summers [23]

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