APPLYING SYSTEMS ENGINEERING PRINCIPLES TOWARDS DEVELOPING DEFENCE CAPABILITIES

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ABSTRACT

Due to high cost of defence systems and the advent of multi-role military platforms, defence forces can no longer replace old systems with similar newer systems, but need to effectively and continually re-evaluate their defence capability requirements to optimise the utilisation of current and future systems. The "cradle-to-grave" System Life Cycle (SLC) process underpinning the Department of Defence (DOD) Acquisition Policy is based on four consecutive phases, namely Planning, Acquisition, Deployment and Disposal. This programme-centric approach is prone to disjunction between present and future systems, and often neglects sufficient emphasis on the requirements definition activity. This paper suggests that a "cradle-to-cradle" Capability Life Cycle (CLC) process can provide junction between current systems in operation and future systems by taking an integrative, capability-centric approach toward the phasing out and renewal of systems. The SLC and CLC processes can be unified by observing that the Disposal phase does not follow on the Deployment Phase, but in actual fact is the outcome of the Planning Phase. It is contended that the CLC process, based on sound SE principles, offers a superior approach toward capability development and sustainment, resulting in a more cost-effective (smaller and optimised) defence capability.

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1. BACKGROUND

The impact of the end of the cold war in the late 80s is still being felt in defence forces across the globe. A predictable "conventional" threat and a clear delineation between ally and enemy have made way for an "unconventional" and "asymmetric" threat and an unpredictable enemy. These factors have caused a shift in thinking from weapon systems to defence capabilities.

In recent developments, European Union (EU) member states agreed under the Lisbon Treaty to more intensively develop joint defence capacities to enhance their forces' availability, interoperability, flexibility and deployability [1]. The South African National Defence Force (SANDF) Military Strategy [2] also defines a need for a defence capability with similar characteristics. Specifically, it requires a single joint force (including all SANDF Services and Divisions) with three joint strategic capabilities, namely C4I3RS [3], light mobile and conventional warfare. The C4I3RS capability is the essential military sensory and command and control support capability for the entire range of military missions defined in [2].

The South African Department of Defence (DOD) Information Strategy [3] has responded to the requirement of a single joint C4I3RS capability by adopting network enabling approaches to achieve optimal benefit of resources and better synchronisation of events and their consequences.

Following international trends, the SANDF established a Joint Operations (J Ops) Division on 1 August 1997 to support joint, rapid and coordinated military missions. The J Ops Division provides military-strategic force employment direction to the DOD through the development of joint warfare doctrine, identification and development of joint defence capabilities which includes the SANDF joint light mobile and conventional warfare capabilities as required by the SANDF Military Strategy.

2. PROBLEM STATEMENT

Due to high cost of defence systems, defence forces can no longer replace aging and obsolete systems with similar newer systems. Instead, they need to effectively and continually re-evaluate their defence capability requirements to optimise the utilisation of current and future systems.

Advances in communications technology provide the means to develop more integrated, complex and interoperable defence capabilities, which allow sharing of sensor information and optimisation of effects. As a consequence, defence forces are required to develop and manage complex integrated and joint defence capabilities limited by resource constraints. Traditional Systems Engineering (SE) approaches are no longer sufficient; novel approaches are required for effective management and development of military capabilities.

This paper elaborates on new SE approaches that could support the defence force in the management and development of its joint capabilities and proposes a unifying process between Capability Based Planning [11] approaches and the current System Life Cycle (SLC) process in order to perform coherent defence capability management in the South African context.

3. CAPABILITY DEFINED

The Australian DOD defines a capability as:

> *"Capability is the power to achieve a desired operational effect in a nominated environment, within a specified time, and to sustain that effect for a designated period. Capability is generated by Fundamental Inputs to Capability comprising organisation, personnel, collective training, major systems, supplies, facilities, support, command and management."* [9]

The UK DOD defines a capability through defining capability goals that define a tangible military effect with Measures of Effectiveness (MoE) and the quantity of effect needed set against most likely and most demanding scenarios [19]. Furthermore, UK capabilities are realised through Defence Lines of Development (DLoD) which include Training, Equipment, Personnel, Information, Doctrine, Organisation, Infrastructure, Logistics and Interoperability (TEPID-OIL) [21].

The SANDF follows similar approaches and has also defined two dimensions to military capabilities, namely capability attributes and capability elements. Capability attributes are functional attributes describing what the capability must be able to do. The most basic and common capability attributes are:

Effect:	Application of military sources to place any identified target at a disadvantage
Protection:	Measures to protect forces against threats from the enemy
Mobility:	Means to achieve and maintain a position of advantage
Command & Control:	Means to perform planning, tasking and control of forces
Information:	Means to provide situation awareness of the battle space
Sustainment:	Ability to maintain the necessary level and duration of operational activity

[3] Command, Control, Communications, Computers, Information, Intelligence, Infrastructure, Reconnaissance and Surveillance (C4I3RS).

Capability elements are the constituent components of the capability and describe what the capability consists of. These elements are commonly referred to as the POSTEDFIT capability elements, defined as follow:

***P*ersonnel:** Characteristics of the required human resources
***O*rganisation:** Command and Control related characteristics of mission task forces
***S*ustainment:** Characteristics of the logistics, personnel and financial support
***T*raining:** Characteristics of the training required to prepare human resources
***E*quipment:** The type, quantity and characteristics of the defence equipment required
***D*octrine:** Characteristics of the required doctrine, aids, operating procedures etc.
***F*acilities:** Characteristics of the military facilities required
***I*nformation:** Characteristics of required defence intelligence, information and data
***T*echnology:** Characteristics of commercial and/or military technologies required

4. CURRENT SANDF SYSTEMS ENGINEERING PRACTICES

The DOD Process and Procedure for the Acquisition of Armaments (DAP1000) [10] defines an 8-layered systems hierarchy depicted in Figure I to facilitate the definition of system requirements and the acquisition of systems.

System	Level	Explanation
Operational Force	8	
Combat Grouping	7	
User System	6	
Products System	5	
Product	4	
Product Sub system	3	
Components	2	
Materials/Processes	1	

Figure I: SANDF Systems Hierarchy

In the Systems Hierarchy, the User System at Level 6 (L6) is the first instance where a POSTEDFIT view exists, which relates to the elements required to transform a L5 Products System to a L6 User System. Both L6 and 5 systems are managed by the SANDF Services (Army, Navy and Air Force) and Divisions (Medical Services, Command Management Information Systems (CMIS) Division, etc.).

At L7 (Combat Grouping) a joint POSTEDFIT is required to facilitate J Ops, which includes multiple L6 User Systems. Capability requirements definition at L7 is a J Ops Division responsibility.

L8 (Operational Force) requirements relate to strategic capabilities defined in the SANDF Military Strategy [2]. It is clear from implementation evidence that numerous L6 User Systems and L5 Products System developments were unable to produce the required jointness, interoperability and flexibility required for L7 operations.

The SLC process underlying the DOD acquisition process [10] is illustrated in Figure II. Clearly the SLC is a “Cradle to Grave” process, which allows limited interaction to facilitate interoperability for joint capabilities.

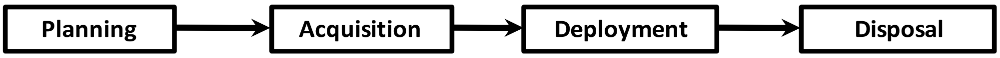

Figure II: SANDF Systems Life Cycle (SLC)

Currently, planning is executed at L6 within the SANDF Services and Divisions, with insufficient means to align this planning with requirements at J Ops level.

In the Acquisition phase requirements are coordinated on a per project basis resulting in L5 acquisition projects managing their requirements in isolation of other projects in the SANDF. The process does not make provision for coordination of capability requirements between Services and Divisions, thus resulting in further disjunction between L6 User Systems and L7 System of Systems (SoS) in the Deployment phase.

Disposal is assumed to logically follow the Deployment phase; in actual fact it is a consequence of re-planning where different options are considered at capability level within the SANDF. Outcomes of a re-planning phase could for instance include upgrading a system, decomposing to modular systems, down grading system functionality, replacement of a system or disposal, to name a few.

It is due to these observations that the authors aim to propose a unifying process to solve the disjunction observed between planning at L7 and L5 in the Systems Hierarchy.

5. CURRENT CAPABILITY BASED PLANNING

As mentioned before, the J Ops Division is responsible to coordinate joint operations for the SANDF. This requires a certain level of Capability Based Planning to direct and guide planning at Services and Division levels in the SANDF.

The SANDF Capability Portfolios are structured as indicated in Figure III – see [12].

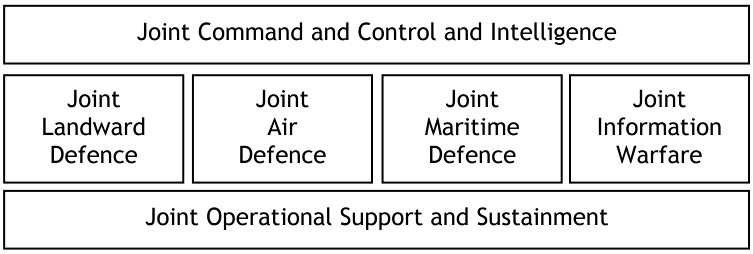

Figure III: SANDF Capability Portfolios

According to a US white paper [11], Capability Based Planning should aim to answer the following questions:

a. What does the joint force need to be prepared to do?
b. How does the DOD assess capability gaps in the joint force and what are the priorities of these gaps?
c. How does the DOD solve capability gaps?
d. How does the DOD manage a Capability Based Force?

In summary, all these questions are aimed at creating some process or guideline to answer one main question; how does the DOD implement Capability Based Planning?

A number of Capability Based Planning challenges have been identified of which the following are applicable in the South African context:

a. There are insufficient implementation directives and guidance
b. Departmental interactions are not clearly defined
c. Areas such as jointness, interoperability and flexibility lack focus
d. Capability Based Planning is difficult to understand and overly complex

This paper addresses these challenges with the objective to provide a framework for unifying SLC processes used in the SANDF and Capability Based Planning philosophies. Disjunction between L7 and L6 is identified as the main area that could improve jointness, interoperability and flexibility of SANDF capabilities.

6. INTERNATIONAL SYSTEMS ENGINEERING TRENDS

The field of SE related to the development of military capabilities evolved extensively over the last years in an attempt to solve capability engineering problems. Neaga, Henshaw and Yue [4] provides valuable insight into these developments and explain how military Capability Based Management has influenced systems engineering into the development of two new fields namely SoS Engineering and Capability Engineering. It is however acknowledged that many disagreements exist on the actual difference between SoSE and SE [4] as referenced in [5] and [6]. For the purposes of this paper, a distinction is made between these two concepts.

For the purposes of this paper, the SE definition from [4], which also relates to the International Council on Systems Engineering (INCOSE) definition of this discipline [7], is adopted:

> *"an engineering discipline whose responsibility is creating and executing an interdisciplinary process to ensure that the customer and stakeholders' needs are satisfied in a high quality, trustworthy, cost efficient and schedule compliant manner throughout a system's entire life cycle."*

In relation to SoSE, the following definition from [4], as derived from [8], is adopted:

> "*cross-system and cross-community process that ensures the development and evolution of mission-oriented capabilities to meet multiple stakeholders' evolving needs across periods of time that exceed the lifetimes of individual systems*".

In terms of Capability Engineering, the following definition is adopted in this paper:

> *"A systemic design approach, with a particular military capability as the system of interest, which synthesises fundamental inputs to create a satisfying result, while considering critically moral, social, economic and political issues. It explicitly addresses changeability and evolvability."* [4]

7. EMERGING CAPABILITY LIFE CYCLE PROCESS FOR SOUTH AFRICA

Oosthuizen and Roodt [13] define an emerging Capability Engineering approach based on the concept of a Capability Life Cycle (CLC) in context of the South African acquisition environment. The CLC typically exceeds the lifetimes of single systems and is regarded as a "cradle to cradle" process rather than a "cradle to grave" process. Note, the requirement for a specific capability can however still be terminated based on critically moral, social, economic and/or political reasons. The CLC, adapted from [13], is depicted in Figure IV.

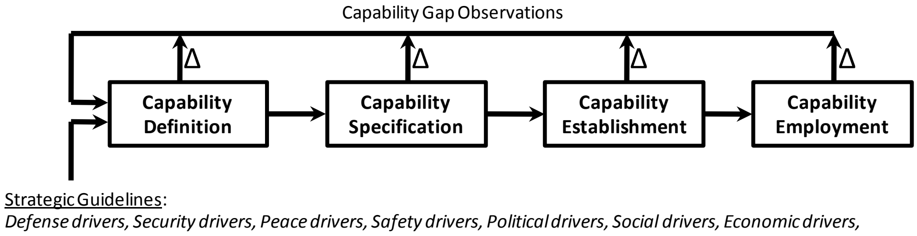

Figure IV: Capability Life Cycle

In this approach the attributes of Capability Based Planning are reflected in that the inputs to the Capability Life Cycle will attempt to answer the question: "How does the DOD implement Capability Based Planning?" The missions that the joint force must be prepared for are derived from the SANDF Military Strategy missions [2], but should also be derived from a Capability Engineering perspective.

The Capability Definition phase attempts to answer the question: "What does the joint force need to be prepared to do?" Capability Specification attempt to answer question: "What are the possible solutions to capability gaps in the joint force?" Capability Establishment attempts to answer the question: "What are the priorities of capability gaps in the acquisition cycle?" Capability Employment attempts to answer the question: "How does the DOD manage a Capability Based Force when preparing for missions and deployments?" This must be done in order to ensure that strategic objectives are met.

Capability gaps are identified, captured and managed throughout the CLC as gaps can be identified in any phase of the life cycle and should be brought to the fore as soon as they are identified so as to make it possible to respond to these gaps. Such gaps could originate due to changes in the expected battlefield, the enemy, available technology, limitations of acquired systems or governmental policy just to mention a few factors.

8. FUNCTIONS REQUIRED FOR UNIFICATION OF THE SLC AND CLC

In an attempt to unify the CLC and SLC processes, it has been established that one would require a number of functions that can be attributed to the field of SoSE. These functions include Architecture Management, Concept Development and Experimentation (CDE), Knowledge Management (KM), as well as a Joint Operational Force Employment function. These functions were derived from [4], [14], [15] and [16]. This is an initial assessment; there might be more functions that are not currently defined.

8.1. Architecture Management

Architecture management can be defined as the information technology discipline that manage the structure of components and systems, their interrelationships and the principles and guidelines governing their design and evolution over time [16]. In general terms architecture management aims to manage:

Alignment:	Ensuring the reality of implemented systems is aligned with the intended capability.
Integration:	Realising that the decision rules are consistent between Services and Divisions that the data and its use are immutable, interfaces and information flow are standardised and connectivity and interoperability are managed across capabilities.
Change:	Facilitating and managing change to any aspect of the capability.
Time to Deployment:	Reducing systems development, application generation, modernisation timeframes and resource requirements.

Convergence: Striving towards a standard Combat Management Information Systems portfolio.

Architecture management can be regarded as the glue that links all phases of the CLC and SLC to ensure a consistent capability is developed from conception to deployment and that any evolution that takes place is documented and the impact on the capability is quantifiable. Design standards and interoperability specifications are also outcomes of this area of interest.

8.2. Concept Development and Experimentation

CDE is a process of learning that supports current and future force developments through a twin-path approach of concept development and prototyping. It should be employed in the Capability Definition and Capability Specification phases and are used to identify capability gaps and to develop solutions to these capability gaps.

These activities include development of probable joint mission scenarios and utilises simulation, modelling, experimentation, prototyping, war gaming, emerging ideas and technologies to execute these scenarios to establish if the required capability attributes are attainable. CDE is the basis for determining the capabilities required for the future force.

CDE activities are driven by a combination of inputs and priorities from J Ops Division, CMIS Division and the capability and plans directorates in the different Services and Divisions. Outputs from this area of interest would include requirements for specific L5 systems.

8.3. Joint Operational Force Employment

This skill is the culmination of knowledge and experience of war fighting commanders to design a joint deployable force for a specific operation or mission based on what functionality joint information exchange architectures will allow, what has been proven possible and viable through concept development and experimentation and what knowledge has been captured in regards to similar deployments in the past.

This is the practical application of the SoS required to execute an operational mission, drawing on all available SoSE resources.

8.4. Knowledge Management

A systematically defined and well-established body of knowledge (BoK) covering war fighting concepts and their successful use has become a major objective of Defence as it begins to tackle issues of KM [15]. Defence forces worldwide have identified an increasing need to develop a KM environment in order to capture, manage, and make accessible knowledge from diverse, yet related, activities to improve operational concepts, systems and processes.

Whilst KM can be expanded to the acquisition or other domains, the focus in this paper is on operational war fighting knowledge in order to simplify the unification theory proposed [17]. The KM depicted in Figure VI supports the process of assessing capability through all life cycle phases.

9. PROPOSED UNIFIED PROCESS

Based on international SE and SoSE trends [4], three main areas of engineering are defined in order to relate Capability Based Planning to the SANDF Systems Hierarchy [10]. These are Capability Engineering, SoSE and SE, which support activities at different hierarchy levels as indicated in Figure V.

In the South African context, the establishment of the J Ops Division initiated the move towards Capability Based Planning in the SANDF following approaches similar to the US Armed Forces under the Goldwater-Nicholls Reorganisation Act of 1986 [18]. Additionally, developments in Capability Engineering in the South African DOD led to the proposed CLC indicated in Figure IV, adapted from [13].

Two of the most prominent issues being observed at present are a lack of interoperability between L5 Products and ineffective User Systems at L6 and L7. The former is due to inadequate coordination and interoperability requirement directives and standards from L7; hence acquisition programmes (most notoriously the Strategic Defence Procurement Packages) are for all intents and purposes executed in isolation of one another. Ineffective User Systems are ascribed to a lack of a holistic view, i.e. POSTEDFIT capability elements are insufficiently addressed. This dire situation is attributed to a disjunction between L7/6 SANDF Capability Based Planning (capability engineering) approaches and L5 acquisition (systems engineering) processes defined in DAP1000 [10].

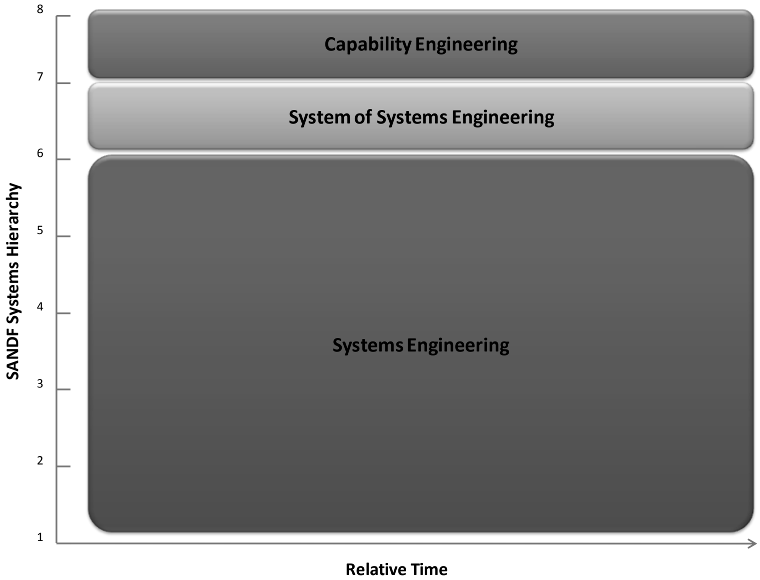

Figure V: Engineering Areas required to perform Capability Based Planning for Defence

A unifying process is proposed to incorporate SoS engineering approaches to bridge the gap between capability engineering and systems engineering. These approaches include JCDE, Joint Architecture Management (JAM), Joint Operational Knowledge Management (JOKM) and Joint Operational Force Employment (JOFE) as described in this paper. This process aims to unify Capability Based Planning approaches by J Ops Division and CMIS Division towards developing joint capabilities to unite Services and Divisions in the battlefield. This process will aid in deriving L7/6 requirements to direct and guide L5 and below acquisition in terms of jointness, flexibility, interoperability and joint deployability. These requirements can then be executed by acquisition programmes by means of the existing DOD systems engineering processes [10].

As mentioned earlier, the SANDF SLC includes a disposal phase, as indicated in Figure II. The unifying process does not display this phase as it is contended that disposal is but one of the possible outcomes of capability specification and systems planning for a specific system where other outcomes in this context could include system upgrading, downgrading, system integration into other systems, or modernisation, to name but a few. All these alternatives have direct impact on the specification of the current required capability and should be evaluated in this phase on a cyclical basis. Disposal should never be executed without evaluating the impact on the capability and planning should be performed for this impact accordingly.

Figure VI illustrates the proposed unifying process, which is explained in the following sub-paragraphs – the paragraph numbers correspond with the numbers in the sketch.

1. Strategic guidelines provided to the SANDF by Government are captured in the Military Strategy [2] in the form of Military Strategic Objectives. These guidelines determine the national defence posture and serve as overarching input to the scope and design of the defence capability.
2. The Capability Definition phase is initiated by strategic guidelines and capability gaps identified in the As-Is J Ops capability. In this phase the DOD identifies what capability gaps exist and prioritises them in accordance with strategic guidelines. Benchmark operational missions and scenarios (including operational/support concepts, operational/physical environments, etc.) are defined in order to provide context to the capability development environment. Joint Concept Development and Experimentation (JCDE) is utilised to verify and define the capability gaps which trigger the Capability Specification phase. The output of the Capability Definition phase will be verified and validated capability gaps that are commonly defined as Required Operational Capability (ROC) statements. These ROC's are handed over to Capability Specification for further refinement.
3. In the Capability Specification phase specific and detailed Concepts of Operations (CONOPSs) are derived for benchmark (typically joint) missions and scenarios. This process may lead to the discovery of further capability gaps, which are fed back to the Capability Definition phase. These scenarios are explored in the JCDE environment were the As-Is J Ops capability is virtually augmented to define particular capability requirements that could solve the capability gaps. Solutions must be specified to be coherent with capability architecture guidelines defined in Joint Architecture Management, as well as with planned L5 systems being specified in detail in the SLC Planning phase. These activities follow a hand-shake activity rather than a hand-over process, which is done to ensure interoperability of systems. These solutions result in Requirement Specifications that are handed over to Capability Establishment for acquisition.
4. The Systems Planning phase entails promulgating the ROC statements to the Services and Divisions of the SANDF. Responsibility for a specific requirement is negotiated and the responsible Service or Division accepts accountability to solve the capability gap through defining an appropriate

requirements specification to acquire or augment systems. The Service or Division shall also ensure that the systems shall be able to be employed in joint operations through performing JCDE activities with capability engineering and JAM stakeholders.

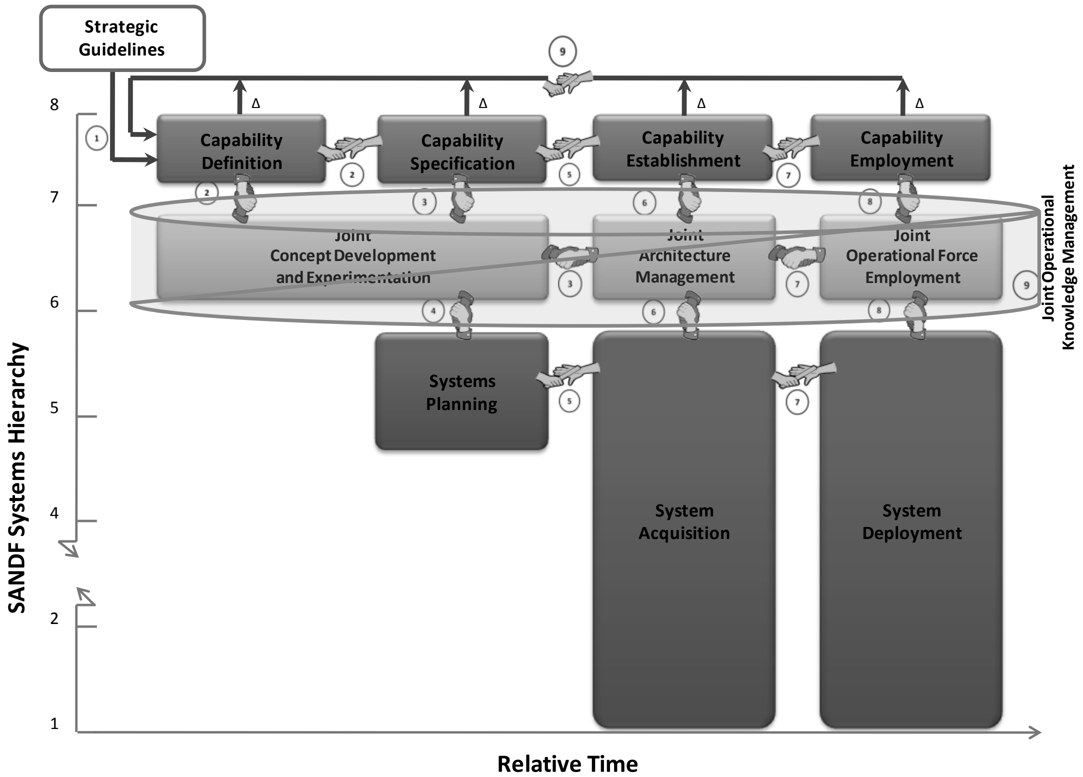

Figure VI: Unifying SANDF Capability Development Process

5. Once ownership of requirements are finalised and requirement statements have been developed in a hand-shake fashion with JCDE, a project team including the acquisition agency takes ownership of contracting and contract management of the project according to current practices in DAP1000 [10]. Capability Establishment is responsible to prioritise acquisition projects in relation to the operational urgency of specific capabilities.

6. Supplementary to current DAP1000 [10] practice, periodical verification and validation activities must be conducted during the system acquisition phase in order to ensure compliance to JAM requirements. The architecture of new systems must be included in the As-Is baseline of joint DOD architecture after completion of a project. New guidelines might also be added from a Capability Establishment point of view as the DOD becomes more network-enabled in nature. These additions should follow phased approaches to avoid changing architecture requirements and baselines as projects are evolving. If acquisition restrictions impact the scope of a project to the extent that a capability gap is created, the capability gap is fed to the Capability Definition phase.

7. Once a project has completed its commissioning phase as per the normal SE processes (L5/L6), an additional commissioning activity is preformed in the form of a “Release to J Ops” validation activity. This activity should ensure that the L7 capability gap has been effectively eliminated. A reference implementation of the new system must be part of the Operating Baseline (OBL) delivery of the new system where it becomes part of the JCDE environment and an augmented As-Is J Ops capability baseline for future experimentation purposes. Capability gaps identified during this phase are fed to the Capability Definition phase.

8. Once a new system is released into service, JOFE takes place where the system is utilised in joint deployments. JOFE should use an up-to-date capability matrix maintained by Capability Employment in order to keep track of all available capabilities. JOFE must also be aware of the limitations and possibilities of assembling a joint force for a specific mission or operation based on the possibilities of the As-Is joint architecture. JCDE contributes to and utilises the JOKM database so as to benefit from experimental scenarios tested, previous architecture topologies employed and previous operational lessons learned.

9. The SoS approach comprising JCDE, JAM, JOKM and JOFE activities provides a means to manage L7 capabilities at the joint operations level. Capability gaps in the As-Is J Ops capability arising from factors such as changes in the operational environment (threat, theatres of operation, etc.), new technology insertion and obsolescence can be identified. These capability gaps are analysed in the Capability Definition phase and will be aligned to current strategic guidelines. As shown in Figure VI,

the process also deals with gaps originating in the Capability Specification, Capability Establishment and Capability Employment phases of the CLC.

10. IMPLEMENTATION GUIDANCE

The US DOD White Paper on Capability Based Planning [11] defines the challenges experienced in relation to implementing Capability Based Planning philosophies in the US DOD. The four biggest challenges are identified as:

a. A lack of implementation guidance
b. Interactions between divisions and services are not defined
c. Capability Based Planning elements lack focus
d. Capability Based Planning is overly complex and difficult to understand

In relation to these challenges it is the authors' belief that this paper provides implementation guidance and a newly acquired focus on the capability management domain, one which does not fall foul of overly complex definitions and explanations of Capability Based Planning in SANDF context.

11. CONCLUSION

This paper proposes a unifying process that resolves disjunction between military capability planning and the systems being acquired to realise such capabilities. This paper cannot prescribe the Services and Divisional interaction structure required within the SANDF to make this philosophy a reality. As described in [11], such structures are, however, fundamental to providing a basis for implementation of this proposed process.

It is believed that a unifying process for Capability Based Planning in SANDF context is an achievable goal. The proposed process provides coherence and consistency of SANDF capabilities by bridging the gap between L7 capability and L5 system levels. Furthermore, the process does not require drastic adaptation to current SE processes adopted in the DOD. It will, however, require some enhancements to the DAP1000 processes in order to establish alignment and integration with the Capability Based Planning approached at J Ops level.

Additionally, some the Defence Evaluation and Research Institutes (DERI) of the SANDF could already provide the capabilities to perform SoSE functions described in this paper.

The relationships between stakeholders will however have to be formalised to ensure that all role players are aware of their required contributions and responsibilities.

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