Application of Systems Engineering: An Acquisition Agent Perspective

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Abstract. This article covers a descriptive case study on the application of systems engineering and systems engineering management at Armscor. The report also covers the investigation into development methods used and the how the requirements changes are managed during the concept phase.

The systems engineering process model used by Armscor is compared with best practice. The Systems Engineering Management Base Theory (SEMBASE) model is used to compare the Armscor systems engineering management practice with.

The study encompassed development methods, requirements management change, design for changeability and use of tools.

Research questions are addressed by narrative analysis. Data is collected from multiple sources: interviews, archival records documentation and observations of enterprise governance documentation.

The data produced during the inquiry revealed that a correlation exists between systems engineering best practices, international standards, the systems engineering process and systems engineering management process followed by Armscor. Requirements changes are managed during the concept Phase and different developmental models are used to execute projects.

Keywords: Systems engineering process, systems engineering management, development methods, defence industry, case study.

Introduction

Armscor acquires defence matériel for the South African Department of Defence (DOD) and for any organ of the state that may require such services.

The acquisition management role can be broadly divided into the following four categories: Systems acquisition management, procurement management, product systems management, and technology acquisition management.

Armscor Acquisition’s enterprise process consists of four main processes and four enabling processes. Figure 1, depicts the relation of the various processes. The main processes apply to the types of project conducted within the enterprise and are mutually exclusive. The enabling processes are cross cutting among the main processes and also throughout the project life-cycle.

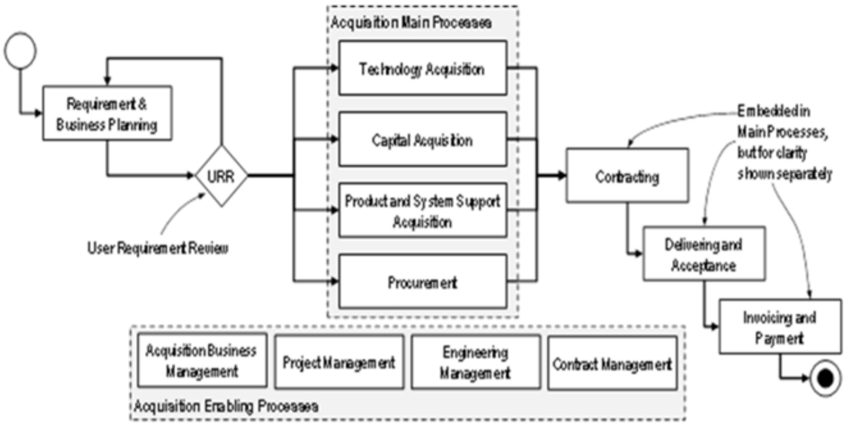

Figure 1. Armscor Acquisition processes

Systems engineering is a sub-set of engineering management and entails the disciplined guide to the engineering of a complex system (Kossiakoff, 2011). Although systems engineering activities in Armscor are conducted throughout the project lifecycle, it is mostly concentrated in the concept phase. The effort is placed in the early stages of the project to produce a system requirement specification and support the establishment of a well-defined contract. The research focus was on the systems engineering activities of the concept phase of the acquisition process.

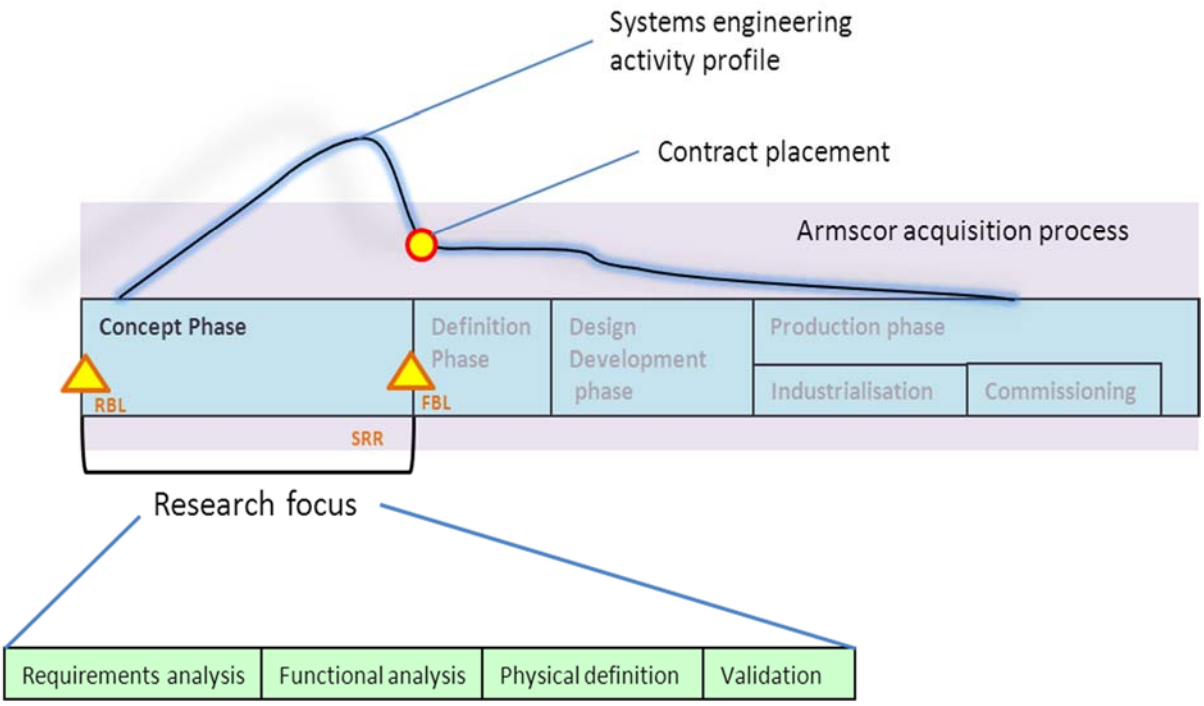

Figure 2. Research focus

Objective

The objective of the research was to test the degree of application of the systems engineering process in Armscor, during the concept phase, and to evaluate the SEMBASE theory in an acquisition type organisation. The following research questions were asked to answer to the objective:

1. Are the Armscor systems engineering processes comparable with best practices and international standards?
2. Are the Armscor systems engineering processes comparable with the SEMBASE theory for systems engineering management?
3. Does the Armscor systems engineering processes and methods support the management of changing technological and operational requirements during acquisition?

Importance of the problem

Systems engineering is an integral and mandated part of the acquisition process.
It is moreover in the interest of Armscor as the custodian on the level 5 tier in the systems hierarchy and specifier of the technical solution, that an effective systems engineering process and systems engineering management process be in place to serve the immediate and long-term needs of the client. Although this research was not directly intended as part of a greater research programme into the SEMBASE theory, the results of this empirical research will contribute the validation and understanding of the SEMBASE theory proposed by Erasmus and Doeben-Heinsch, (2011).

Conceptual method

For the research a summary review was first conducted of the work by Mgoza (2012) and Nyareli (2012) within the defence related industries, covering a comparison of ISO 15288 and ISO 26706 to typical level 4 systems engineering process and systems engineering management processes. This was followed by a review of the systems engineering process models as proposed by the INCOSE Systems Engineering Handbook v3.2.2 (2011) and Kossiakoff (2011). The research included a discussion on the analytical systems engineering methods used to establish a base from which to manage systems change. The final part of the research evaluates the Armscor SEM process and compares it to the SEMBASE model.
The investigation into the systems engineering process looked at the overall application of the core processes of requirements analysis, functional analysis, physical definition (synthesis) and validation. Each of the sub-sets of the systems engineering process was then investigated in detailed level. A qualitative investigation into the application of the SEMBASE theory was done to evaluate the systems engineering management process practiced in Armscor.

Literature study

The definition of systems varies among disciplines but for the purposes of this research it will be contained to man-made systems. INCOSE (INCOSE Systems Engineering Handbook v 3.2.2(2011) defines systems as:

"an integrated set of elements, subsystems, or assemblies that accomplish a defined objective. These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements."

System Hierarchy. A characteristic of a system is that is resides within a hierarchy of layers, each layer more complex than the lower level (ISO/IEC15288, 2008). The layers in the hierarchy are differentiated by the degree of complexity of emergent prosperity of the system elements.

The DOD demarcation of a systems hierarchy and its responsible party is presented in figure 3.

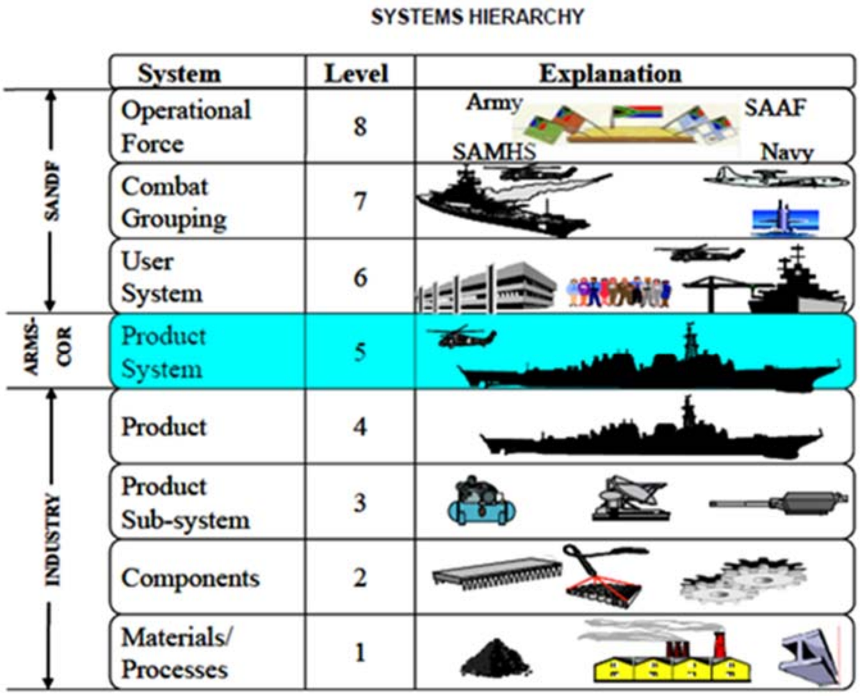

Figure 3. DOD systems hierarchy (source DAP 1000)

The life cycle model. ISO/IEC 15288: 2008 describes the systems life cycle as an abstract functional model that represents the conceptualisation of a need, its realisation, utilisation, evolution and disposal.

It further relates to the maturing of a system as caused by the actions and performed and managed by people in organisations using processes. Figure 4 depicts the DOD acquisition life cycle.

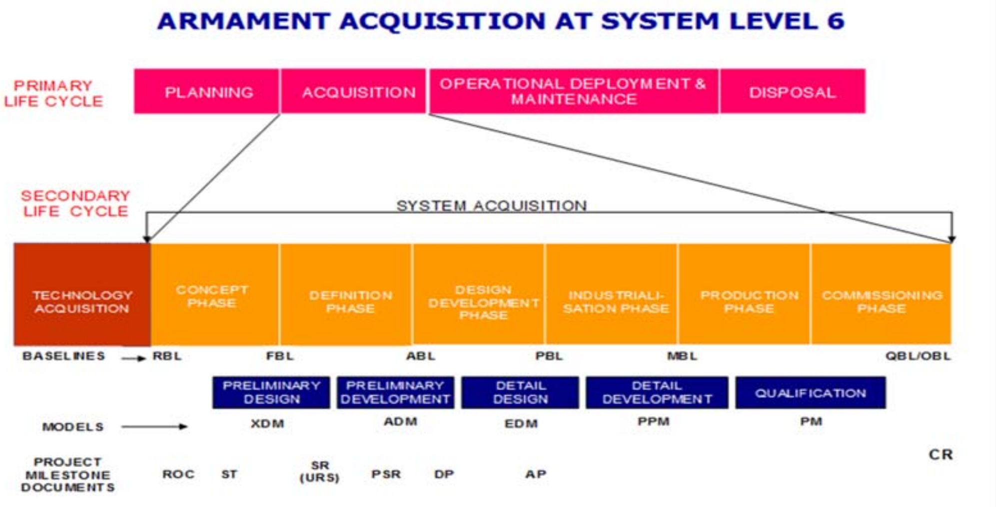

Figure 4. Acquisition lifecycle (source DAP 1000)

Development models. A variety of methods are used to develop systems solutions. The variation in methods is due to the diverse requirements of technical projects. Joseph-Malherbe (2012), refers to the purpose of a development method as a means to successfully design and develop a system, congruent to its character. Mgoza (2012), discusses and compares so-called traditional development models and shows their respective strengths and weaknesses.

Factors other than the project character that impact the choice of development method are technical and team considerations as well as the organisational environment, Lemétyer in Joseph-Malherbe, (2012). Boehm and Turner, (2003) identify the following five factors that impact the development method choice. Team size, personnel skill level, task risk, organisational culture and dynamism of the rate of change

Standards in systems engineering. Standards are documents that establishes engineering and technical norms for processes, procedures, practices and methods that have been adopted as standard. The salient content of systems engineering standards are summarised by Viljoen (2008) as follows:

- ISO/IEC 15288: 2008 as a framework for describing the life cycle of systems. Reference is made to the fact that this standard is not prescriptive to the methods or procedures used in its application. The research interest in this standard is the management of the life cycle processes and the technical processes.
- ISO26702/ IEEE 1220, provides the details of the systems definition and management of the technical processes but does not present a system life cycle process. It is suggested that ISO/IEC 15288 and ISO 26702 are used complementary to each other.
- EIA-632 deals with the requirements for system realisation as the area of research focus of this research is on the systems concept stage, the detailed requirements presented in this standard are outside the scope of this research (product realisation occurs at a later stage)

Figure 5 shows the realation among the system engineering process, standards and development method.

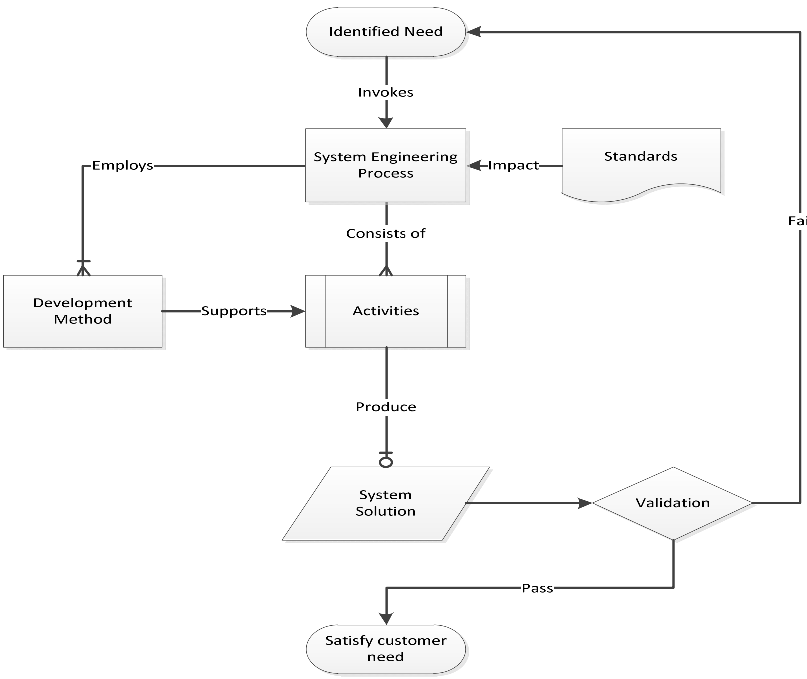

Figure 5. System engineering, standards and development method relationship diagram

Systems Engineering Management. The SEMBASE model, as depicted in figure 6, views the interaction between life cycle integration and the SEP as an integrated model.

The life cycle integration allows the client requirements to be incorporated into the systems solution by initiating the ROC. Actors in the SEM process, stakeholders (S) and experts (ε) who are responsible for all the product life cycle stages are involved early in the development of the system requirement. This enables concurrent engineering of the system.(Erasmus & Doeben-Henisch, 2011).

The development phasing defines the systems hierarchy by successive application of the SEP. The highest system level delivers, as output of the SEP on that level, the requirements for the next lower level (Course material: Acquisition Management, Sparrius, 2013). The development phases, concept (P_c), system definition (P_s), preliminary design (P_{ss}) and detail design (P_{sc}) are successively matured by the application of the SEP for each life cycle phase. The SEP is concurrently applied to each life cycle integration phase, initiated by requirements (R) and concluded by a model (M) for the specific development phase. Requirements for the development phases are, concept (R_c), system definition (R_s), preliminary design (R_{ss}) and detail design (R_{sc}). Models resulting from the SEP are concept (M_{s*}^{c}), system definition (M_{s*}^{s}), preliminary design (M_{s*}^{ss}), and detail design (M_{s*}^{sc}) (Erasmus & Doeben-Henisch, 2011).

As with the traditional systems engineering approach and the model based approach, SEMBASE uses models to verify the design against the requirements. systems level validation occurs as at each development phase. As an example, the concept model (M_{s*}^{c}) will be used to verify and validate (V&V) the concept requirements (R_c). The concluding model of the development phase (M_s) is used for overall validation of all life cycle phases.

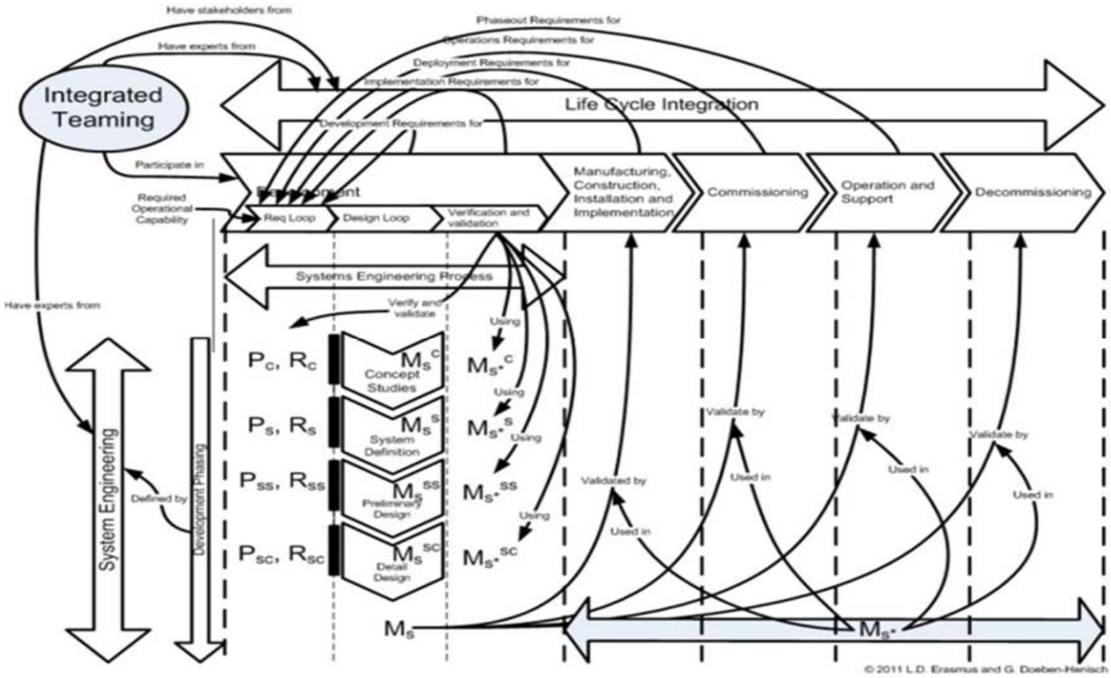

Figure 6. SEMBASE model for Systems Engineering Management (Erasmus and Doeben-Heinsch, 2011)

Change affecting Systems Engineering. Business has become increasingly complex over the past decades. This trend is poised to increase in the foreseeable future. Wenzel et al in (Schultz, et al, 2000) identify three aspects as major drivers for future systems development. Similar factors are identified in Kossiakoff et al (2011). The major factors influencing future systems design are given as:

- Dynamic markets, which could be compared to the dynamic operational environment and new military threats. High numbers of new threats are emerging, while older and more well-known threats are changing.
- Pace of technology evolving more rapidly than the intended systems life-cycle. Furthermore, the functions of systems are evolving rapidly within the life cycle.
- Variety of environments, created by the greater emphasis for systems to operate in a system of systems role.

Major military systems are of high value and have long life expectancy. These types of systems will invariably be subject to the driving forces discussed above. Ross et al, 2008, defines these systems as robust systems with the following sub-characteristics:

- Capable of adapting to changes in mission and requirements

- Expandable/scalable, and designed to accommodate growth in capability
- Able to reliably function given changes in threats and environment
- Affordable: Effectively/affordably sustainable over their lifecycle
- Developed using products designed for use in various platforms/systems
- Easily modified to leverage new technologies

Steiner, (1998), suggests the use of enduring architectures as a means of managing the change in systems design.

Research methodology

The case study method for doing research involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence (Saunders *et al*, 2007).

This research method was chosen as no specific systems engineering governance practice existed at the time and a deeper understanding of the application of systems engineering was investigated.

In this case study the principles of triangulation (Blumburg et al, 2008) are used to find validation of the gathered data. The first node of the triangulation draws a grouped comparison of best practices in systems engineering, as found in literature and contemporary standards. Mapping carried out by Mgoza, (2012) and Nyarelli, (2013) for level 4 defence industry enterprises was used as a point of departure to further map the best practice and standards to the governance procedures and practices used by Armscor. This node determined Armscor's systems engineering alignment with best practices and standards. Interviews conducted with a sample of the technical population in Armscor formed the second data node, reflecting the experience of personnel using systems engineering processes. The third node of the triangulation was a data search in project document to validate the outcome of the interview results.

For this research the unit of analysis were projects conducted in Armscor, with the focus on the practices and processes followed during the concept phase of the systems life cycle.

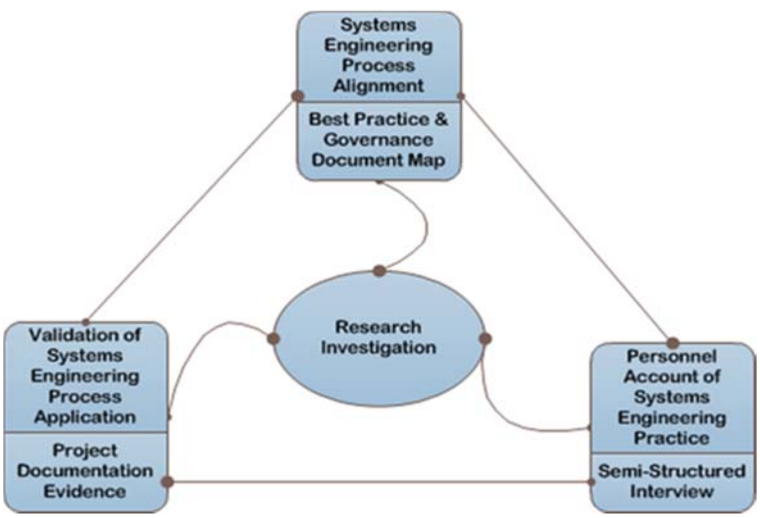

Figure 7. Case study triangulation

Interview sample

The composition of the sample population and sample size was determined after the initial survey. A mixture of complex and non-complex current projects and a spread of personnel experience were targeted for the sample. Some specific, systems engineering intense projects were selected for investigation.
Additional factors impacting the judgemental sample were that projects had to be current projects in Armscor and had to be selected from the Business Register. The basis of the selection was the type of project, systems engineering involvement, and the availability of the project manager/systems engineer. All the projects selected were post Requirements Baseline capital acquisition projects as the application of systems engineering is the greatest in capital acquisition projects between the requirements baseline and the functional baseline. This deviation from the planned survey was necessitated by a very low initial response rate. Figure 8 displays the composition of the sample group used for the interviews.

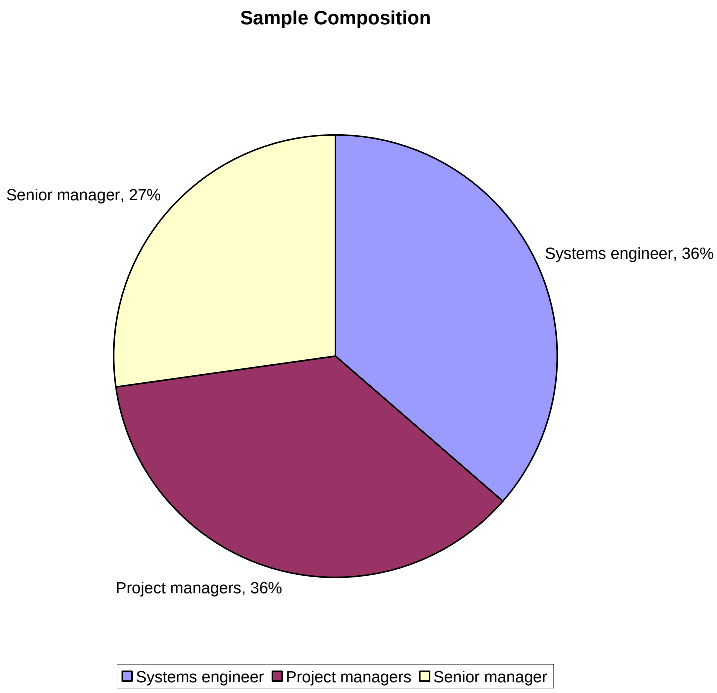

Figure 8. Sample composition

Results

Governance documentation and best practices results

DAP 1000, which is regarded as the acquisition handbook of the South African defence industry, has a broad, high-level description of systems engineering principles that are to be followed during the Acquisition process.

Principles that could be related to the level of detail that the research intended to measure were extracted and are presented in table 1, DAP 1000 vs Kossiakoff, below.
In a word search of RSA-MIL-3, the Armscor baseline management handbook, no specific mention of systems engineering was found other than the nomenclature of Systems Engineering Management Plan (SEMP). Other documentation investigated was the A-Prac-1024, Systems Acquisition Practice. Of these documents, DAP 1000 compared strongest to Kossiakoff.

Table 1: DAP 1000 vs Kossiakoff, for Requirements Management

	DAP 1000, Requirement Management	Kossiakoff
1	identification,	X
2	derivation,	X
3	allocation, and control	X
4	traceable,	
5	comparable,	X
6	verifiable manner	X
7	system functions,	X
8	attributes,	
9	interfaces	X
10	and verification methods	X

Interview results

Systems engineering process. The inquiry into the systems engineering process that was followed during project execution delivered divergent responses.
Nine respondents partially applied the elements of the systems engineering process. This partial application to the systems engineering process was attributed to user documentation constraints, requirement quality and perceived contractor responsibility.
The two respondents that had followed all the activities of the systems engineering process on their respective projects were executing systems engineers responsible for the delivery of systems specifications.

Requirements analysis. There was a distinct division in the respondent's answers of the project managers and systems engineers with regard to requirements analysis. The project managers indicated that requirements analysis was the domain of the user and that no further analysis was necessary. In contrast systems engineers felt that requirements analysis was poorly done and could be improved. A common remark related to the quality of the requirements. In three cases, the respondents felt that the requirements were too constraining and contained too much design detail.

Functional analysis. Functional analysis was sparsely done and was stronger noted among systems engineers than project managers. It was found that functions are seldom decomposed

lower than system segment level and the method used to do the derivation of requirements to functions is based on experience and judgement.
A notable lack of activity was observed in this sub-set among the project managers. This could be attributed to the contracting of this work to external systems engineers.

Physical definition (synthesis). The elaboration of design architecture was strongly considered a contractor function and only three respondents reported expanding the architecture to lower levels of the design.
Synthesis of alternate designs was done by soliciting technology and product information from suppliers and allocating the alternative designs to functions. All the respondents used the same process. A formal Request for Information (RFI) process was followed and was preceded by a baseline review. The available concepts were then traded off with a value system, based on systems effectiveness.

Design validation. Verification and validation were considered activities that were to be performed during design and development as developmental or operational tests. Validation was considered a user function and was to be performed after product design qualification. Four respondents used all the methods for design validation during the concept phase to validate the design. Design reviews were the method of validation that was used most. Validation of the design content was done at four instances of review, the Systems Requirements Review (SRS), the Functional Baseline Review (FBL), Quality Audit and the Project Study presentation.

Systems **engineering management**. Systems Engineering Management principles as described in the SEMBASE theory (Erasmus and Doeben-Heinsch, 2011) were well used in the established enterprise processes and culture. All respondents reported positive to inclusion of the SEMBASE theory activities as derived in Nyarelli (2012) and adapted for the concept phase.

Development process. The DAP 1000 and RSA-MIL-STD 3 make no specific reference to a developmental method for the application of the systems engineering process. The view of the respondents was that the governance documentation favours the waterfall method over other methods.
The spiral method was used in two cases to develop requirements before embarking on a waterfall development. Figure 9 illustrates this approach.
Another notable case was the use of rapid prototyping during acquisition as depicted in figure 10. This essentially involved the spiral development of a specific component while the rest of the systems items followed a waterfall development.
One manager supported spiral and incremental development methods as the waterfall method was considered too rigid and did not allow the flexibility of rapid change.

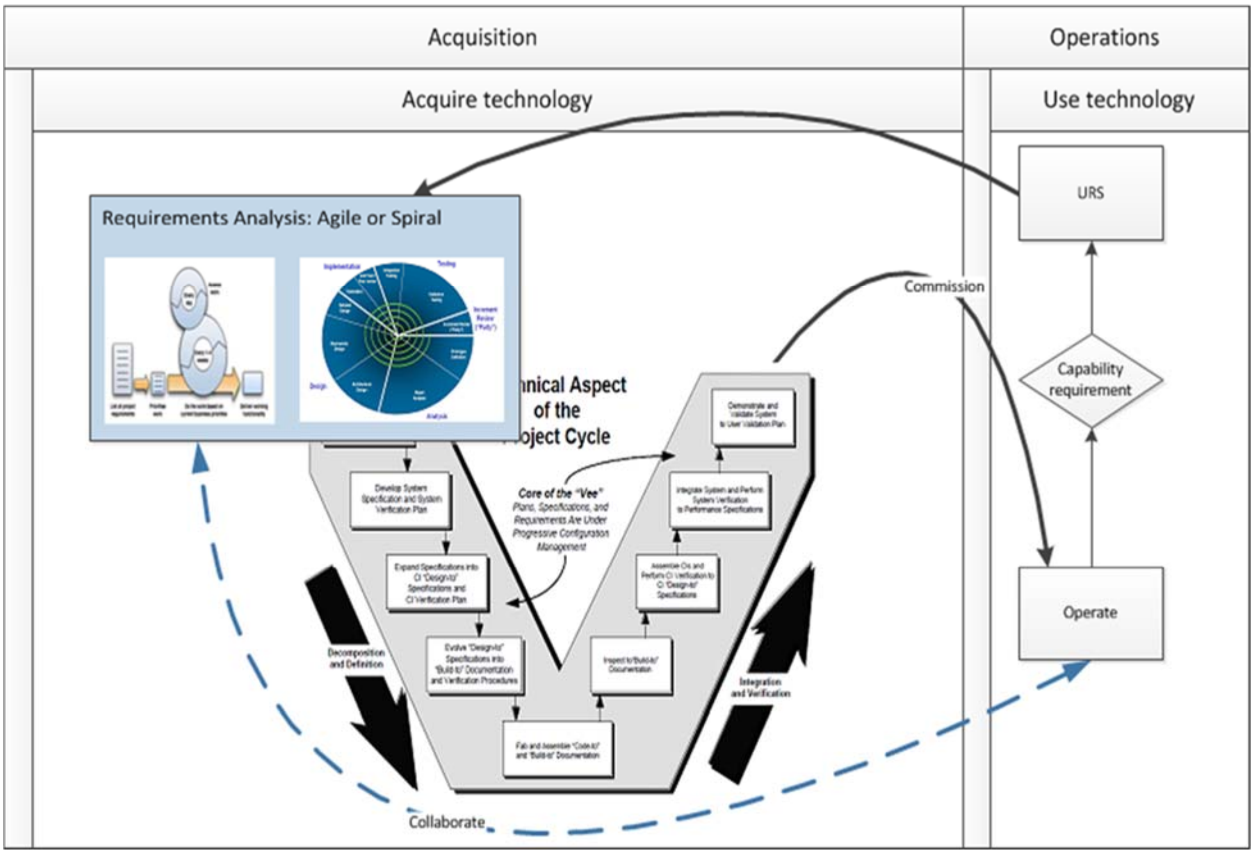

Figure 9. Development approach: Spiral requirements development.

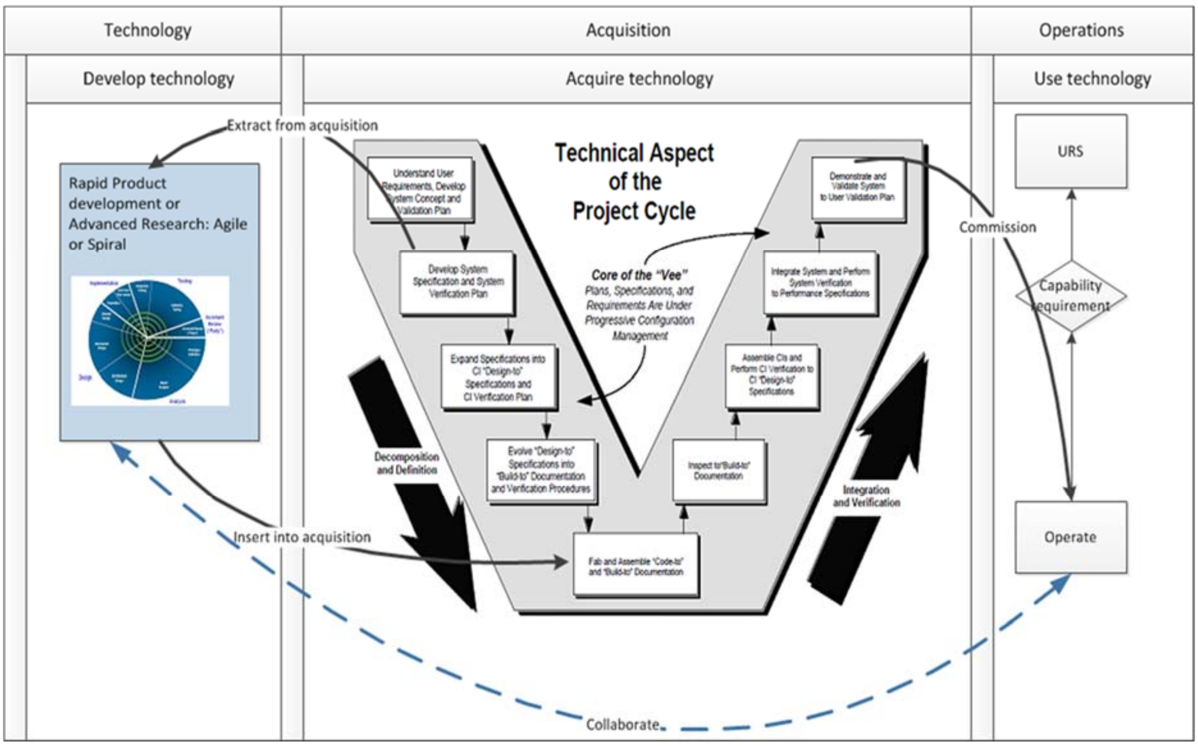

Figure 10. Development approach: Rapid prototyping**.**

Document search results

The documentation search was the final pillar of the triangulation used for the case study. The document search confirmed the interview results to a varying degree. The reported activities were found in the documentation, although scattered.
It was difficult to follow the trail of activities as the information was scattered across documents. The three documents that had the most relevant content in one place were the Project Study Report, the Systems Specification, and the Quality Audit Report.

The systems engineering management plan (SEMP), test and evaluation master plan (TEMP) and integrated logistics support (ILS) documents were found to be the predominant systems engineering management documentation and were used in all the projects investigated. These documents are mandated for functional baseline (FBL) in RSA-MIL-STD 3.
Lacking in all the projects was the technical performance management (TPM) document.
It was noted that no specific documentation repository exists for the various sub-sets of the systems engineering process documentation. This is a deficiency in the documentation architecture and could be of value especially when project data need to be reused or shared.

Conclusions and recommendations

Conclusions

The results of the investigation suggest that there is a correspondence between systems engineering procedures of the Armscor systems engineering process and best practices. There is a culture of systems engineering application among Armscor personnel and systems engineering activities are documented, although scattered and sparsely.

Armscor is an acquisition agency and not a systems house and systems engineering as part of engineering management is an enabling process in support of the enterprise business.

The systems engineering process used by Armscor is designed and tailored for this phase of the systems life cycle. The origins of the Armscor systems engineering process were not investigated but the process was found to have a strong correlation with the systems engineering process as proposed by Kossiakoff for the concept phase (Kossiakoff, 2011). The relation, including some gaps, extends to ISO/IEC 15288 (2008) and INCOSE (2008).

The Systems Engineering Management method correlates to the SEMBASE theory activities as derived from Nyareli (Nyareli, 2012) and used in this research.

A strong perception existed among some respondents that the systems engineering process was the waterfall method of development. Although the waterfall development method is widely used, other methods like Spiral, Agile and Incremental development, although sparsely used, were found to be attractive where requirements needed to be clarified or a product rapidly developed.

Recommendations

Requirements analysis should be improved by including more analytical methods. The addressing of requirements inadequacies should be derived from these analyses and should be encouraged. This recommendation supports the finding in Potgieter, (2005).

The demographics of Armscor are changing rapidly and the reliance on experienced personnel alone is not sustainable (Khuzwayo, 2011). It is suggested that analytical methods, including computer aided methods be encouraged to bridge the gap in experience and contribute to new knowledge and accelerated experience.

A dossier should be created to accommodate the data and documentation resulting from the sub-set activities, analysis and studies resulting for the systems engineering effort, and should be configured as part of the project documentation.
The use of alternate (Spiral, Agile, etc) development methods should be considered as part of the Engineering Management practices. A decision model should be developed to guide the systems engineering strategy.

Future research

A decision model for development method selection should be developed and tested.
Two suggested models exist as concepts in Armscor, the requirements to solution risk model as proposed by Mr J Lötter on 15 August 2013, (not included in reference list) during the interview and the criticality index to cost model as proposed by M Vilakazi (Vilakazi, 2012). A combination of these models could be developed and tested as part of future research.

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Biography

Adrian Niken is an aero-mechanical engineering technologist by profession. He has experience in the areas of design and development, project management, facility management and systems engineering. Adrian's experience in the defence sector was gained through the association with various companies including; SAAF, Denel Dynamics (Kentron), Aerosud and Armscor, where he currently holds a post as a technical manager (Systems Engineering).
He received a B-Tech(Mechanical Engineering) degree from the Tshwane University of Technology (Pretoria Technicon) and graduated with a Master's Degree in Technology Management from the University of Pretoria.
His interests are in the application of systems engineering in the innovation sector and business development in the informal engineering sector.

Louwrence Erasmus worked for more than 20 years on multi-disciplinary projects in academia, South African and international industries. He is a Principal Systems Engineer at the CSIR since 2013. He is an advisory board member of Third Circle Asset Management. He graduated from the Potchefstroom University with the B.Sc., B.Eng., and M.Sc. degrees in 1989, 1991, 1993 and awarded the Ph.D. degree in 2008 from North West University, Potchefstroom. He is a registered professional engineer with ECSAand a senior member of IEEE and SAIEE. His interest is formal structures using constructivist philosophy of science and their practical implications in the practice of systems engineering.