Systems Engineering in the Transformed South African Defence Evaluation and Research Institutes

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First Annual Conference of the South African Chapter of the
International Council On Systems Engineering (INCOSE)
12 & 13 August 2003

Abstract

The paper considers the question whether the transformation in the South African Defence Research Institutes (DERIs) during the 1990's rendered their use of the formal Systems Engineering (SE) processes inappropriate and unaffordable. The historical roots of SE in the SA Defence Research and Development (R&D) Community are discussed as well as the transformation of defence R&D in the SA public service. The application of the scientific and system engineering processes is discussed and the differences pointed out. The importance of tailoring the process to the task at hand is stressed. Finally the conclusion is drawn that both these processes are still very important and valid in the DERI environment.

What is Systems Engineering?

Over the years various views have been aired on the degree of technical (engineering) and management content of engineering a system. Even today one can find a number of different opinions on this issue. For the purpose of this paper however, the definition as found on the International Council on Systems Engineering (INCOSE) website[1] is accepted, namely:

"Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

- Operations
- Performance
- Test
- Manufacturing
- Cost & Schedule
- Training & Support
- Disposal

Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs."

[1] From INCOSE website - http://www.incose.org/whatis.html

Historical roots of SE in the SA Defence R&D Community

SE in the SA Defence environment pretty much followed the US DoD effort (as illustrated in Figure 1) in the definition and application of SE standards over the years. Even before the existence of MIL-STD-499, AFSCM 375-5 Systems Engineering Management Procedures provided some guidance on the subject.

The application of systems engineering standards in the SA defence environment can probably be traced back to the early eighties when Ad Sparrius left the National Institute for Defence Research (NIDR) to study the topic and started developing his now famous training courses. It wasn't until about 1984 that systems engineering was generally accepted and people started using it on a larger scale. Some of the first programmes that applied the formal process were the development of the G5 and G6 artillery systems.

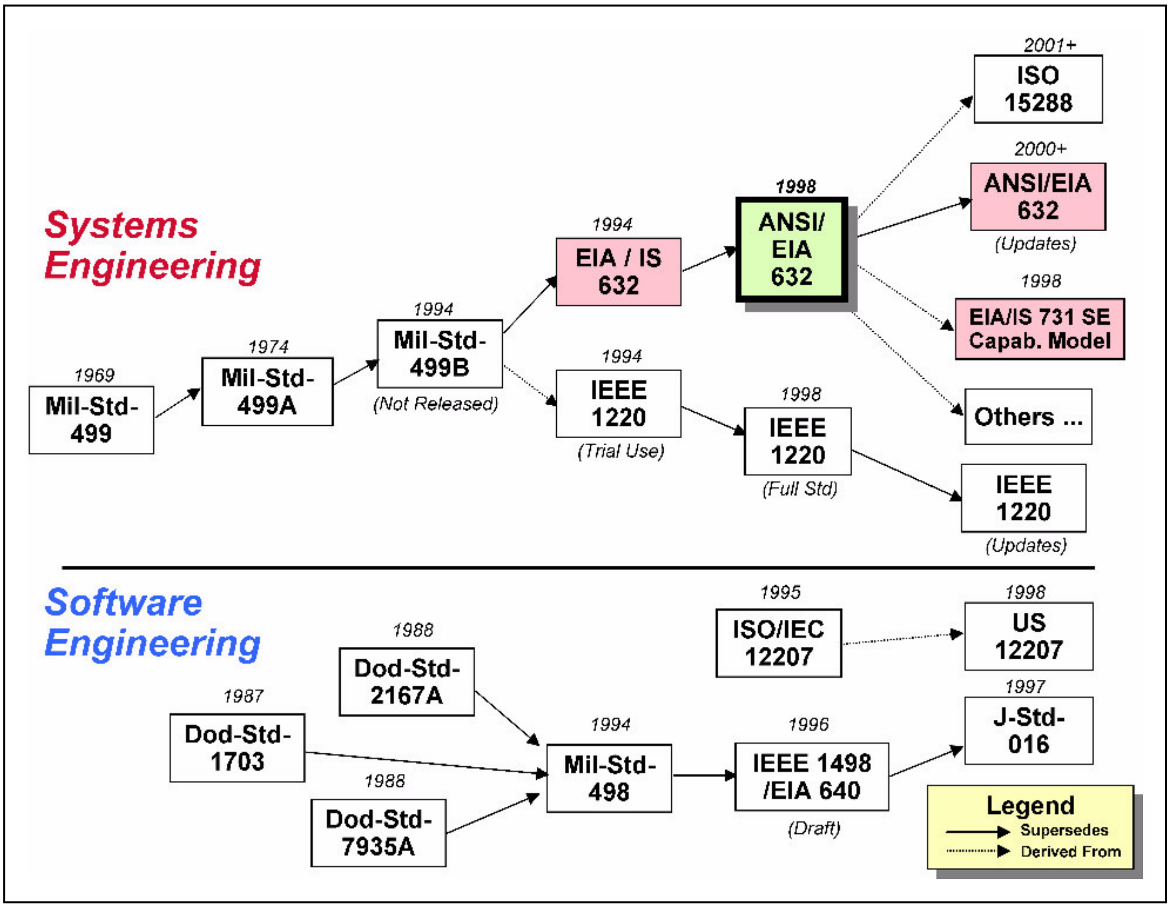

Figure 1 Heritage of Systems Engineering Standards[2]

Systems Engineering in the Defence R&D community during the 1980's

The primary objective of the defence R&D community during the 1960's and 1970's shifted from a pure science approach (applying the scientific process) to one of establishing technology demonstrators for which the technology could be transferred to the then developing arms manufacturing industry. The systems engineering process was not well known and the systems approach to the development of technology was not applied. This

[2] From the INCOSE website – http://www.incose.org/stc/standards_evolution.htm

quite often led to the development of technological advanced products for which the industry then had to consider the other supporting elements during the industrialisation phase. Due to pressure on such developments from the Angolan war effort, many products reached production while issues like logistic support, verification and validation received very little attention. In some cases where the systems approach was applied, insufficient tailoring led to high costs and limited value for money from the process. The learning curve was steep and the road filled with many obstacles.

The transformation of defence R&D in the SA public service

The effects of transformation on the South African defence related industry. Between 1989/90 and 1997/98 the defence budget declined by over 50% in real terms.[3] The dramatic cuts in defence spending threatened the continued existence of an effective Defence Technology Base and it became necessary to fundamentally rethink government's support to the Defence Technology Base.

Government subsequently published its White Paper on the South African Defence Related Industries in December 1999. This document contains a detailed evaluation of the situation and then continues to provide an extensive set of policies and strategies designed to provide guidance on how to handle the situation. The interested reader is well advised to study the relevant chapters in the White Paper.[4]

Defence technology in the South African defence related industry. Recognizing the continued importance of technology in the SANDF, the White Paper on Defence defines from a technological point of view the type of force the SANDF should be. It states that the SANDF will be a balanced, modern, affordable and **technologically advanced** military force, capable of executing its tasks effectively and efficiently (Chapter 2: paragraph 11.7). It further states that the government will not endanger the lives of military personnel through the provision of inadequate or inferior weapons and equipment (Chapter 3: paragraph 43.6).

The importance of Science and Technology as essential components of the government's strategy for creating the South Africa of the future is expanded in detail in the White Paper on Science and Technology. In paragraph 8.2.5 it deals with Defence Research as one of the important operational issues of government funded Science Engineering and Technology Institutions. In this paragraph it draws attention to the fact that the new strategy of the SANDF is to convert the current force into a smaller but technologically more capable one. It states that the dependence on a broad technology base will be high. **The maintenance of a strong Defence Technology Base is therefore identified as a prerequisite of the new SANDF strategy**.[5]

Government Strategy regarding a SA DERI. The White Paper on South African Defence Related Industries states that: "It is neither affordable nor necessary to strive for complete self-sufficiency in armaments production and all the technologies to support it. However, the SANDF requires that in certain strategic areas, limited self-sufficiency must be retained and maintained and that in others, the SANDF needs to remain an informed buyer and user of equipment."

One of the strategies to implement these requirements is to follow the example of many technologically advanced countries and establish what is called a South African Defence Evaluation and Research Institute (SA DERI).

[3] White Paper on the South African Defence Related Industries
[4] White Paper on the South African Defence Related Industries, Chapters 3 to 7.
[5] White Paper on Science and Technology, Preparing for the 21st Century, published by the South African Department of Arts Culture Science and Technology.

Definition of Defence Evaluation and Research

In the White Paper on the South African Defence Related Industries the term Defence Evaluation and Research (DER) is chosen to refer to the whole field of Science and Engineering in which Technology is generated and applied through the performance of Research and/or Development, Test and/or Evaluation, or Operational Research in Defence applications.

In the Department of Defence, the general field of **science and technology (S&T)** is defined as that which is established and developed by a combination of **basic research**, **exploratory development (applied research),** and **advanced development** (Refer to Figure 2). S&T then may be viewed as a dynamic, ever- advancing field of knowledge.

The "Science" part refers to knowledge of the laws and characteristics of the natural world. It also includes mathematical tools and techniques required to describe, model and predict the behaviour of systems based on these laws and characteristics.

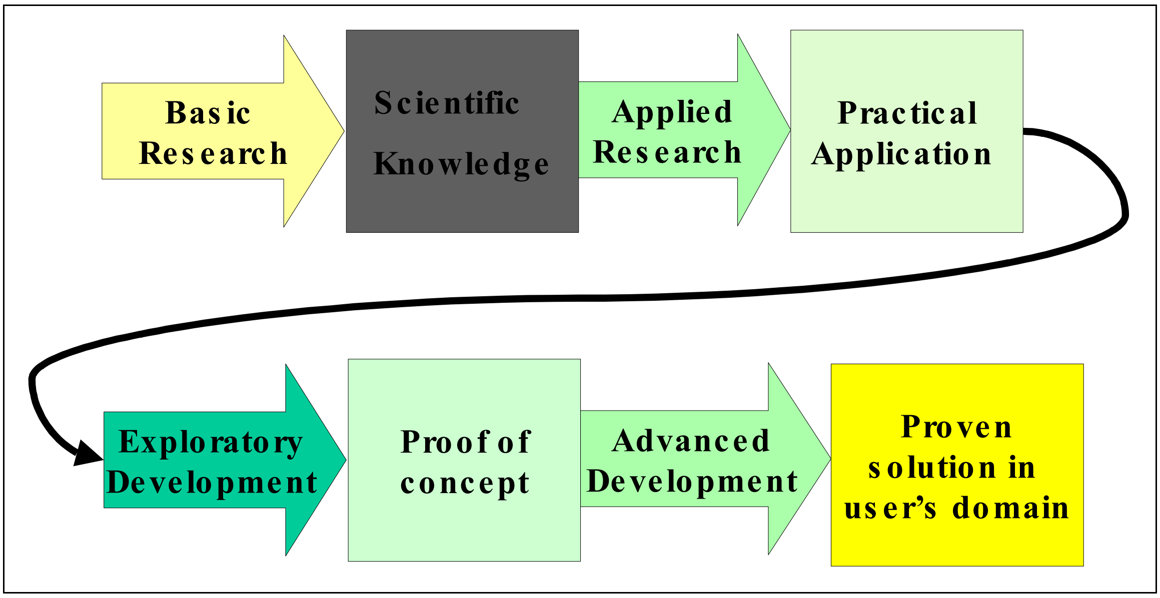

Figure 2 Science and Technology (S&T) established and applied through Research and Development (R&D)

The "Technology" part refers to knowledge employed to design, build, test and use manmade systems, processes or techniques. It is most useful to man when it helps him to solve problems and achieve his goals in the most cost-effective way.

Basic research is considered long-range, non-focused inquiry that advances the state-of-the-art frontiers of fundamental knowledge. Basic research may never have a practical application and is directed toward solving the axiomatic problems of nature.

Applied research is differentiated from basic research in that it has a primary focus toward specific objectives, either as a final product or process. This objective may be to serve a commercial need or to satisfy a requirement in a much larger, more sophisticated system.

Exploratory development is often used interchangeably with applied research. The main goal of exploratory development is to bridge the gap between basic research (that having no practical application) and the initial development of hardware for use in a system.

Advanced development incorporates the initial development of hardware for use in a system. It is structured to directly apply scientific and technological advances to military uses.

CSIR Defencetek was launched by the MoD in 1999 as the largest of the publicly owned organizations specifically structured to provide DERI services to the DoD. It combines several of the Defence Research Capabilities that existed in SA since the early 1960's. Typical examples of Defence Evaluation and Research conducted within Defencetek are:

Basic Research: Defencetek itself conducts no basic research but relies on the universities and other international institutions to obtain information on research results.

Applied Research: The development of advanced ECM/ECCM techniques

Exploratory development: Earlier development of the Fynkyk and Meccano radar technology demonstrators of which the technology was transferred to industry.

Advanced Development: Test and evaluation measurement equipment like Fynkyk, Fynmeet, IRML, Enigma.

The S&T process therefore operates as follows: Discoveries made in basic research are fed into a "base" data bank of knowledge for applied research to exploit. Once the scientific discovery is shown to have some practical application via the exploratory development phase, the military application is tested through the advanced development process. Applied research and advanced development stand on the shoulders of basic research to accomplish their goals in solving a particular problem.

Research and development (R&D) is performed in all the disciplines of science and technology to develop S&T in a systematic manner towards useful products, processes, materials, or systems. Thus, the term R&D describes the actions by which the state of the art of S&T is advanced.

In a defence-related example, the "invention" of new air-to-air missile technology, such as discovering new search algorithms or inventing more energetic and stable missile fuel occurs in the field of S&T. The R&D program associated with developing this new missile includes the testing, evaluation, and assessment of missile performance, including for example the cost of fuel that any carrier airplane may use in conducting these tests. Therefore, the term R&D refers to the process used to achieve the S&T goals. It pulls in all the supporting infrastructure and administrative support necessary to do this.

The Role of DERIs[6]

To ensure the long term effectiveness of a modern, technologically advanced defence capability, a publicly owned and funded defence S&T capability is considered important in most Western democracies. Some of the important categories of the DoD's military capability that require professional S&T support are indicated in Table 1 on the next page. The basic roles of a DERI is to provide professional Science and Technology (S&T) support in the basic categories of Smart Buyer, Smart User and Smart Decision Maker, as well as to provide the basic and/or applied defence research in the state's "in-house" defence S&T capability as reflected in the last column.

[6] Francois Anderson, *Satisfying the DoD's Need for Science and Technology Based Support*, 09/04/2003

Table 1 "In-house" S&T Support Requirements of the DoD

Smart Buyer	Smart User (Adapt to changing environment and requirements)				Smart Decision Maker		Defence R&D
Procurement and Acquisitioning	**OT&E and doctrine development**	**Training**	**Quick reaction services**	**Continuous Improvements**	**Information and Intelligence**	**Policy and Planning**	**Innovation**
Developing capability requirement specifications. Assessing conceptual solutions as part of smart procurement. Reviewing of product specifications in contracts. Conducting design reviews. Representing the "client" at acceptance tests. Supporting simulation based acquisition. Closing verification and qualification loops.	Modelling and Simulation. Testing and Evaluation. Performing "Scientist & soldier" innovation: CONOPS, doctrine and SOPs.	Presenting specialist technical courses. Modelling and simulations.	Problem solving. Front line planning support. Decision support.	Observing, measuring and analysing. Modelling and simulating. Specifying required improvements. Developing improvements. Performing tests and evaluations on improved equipment and procedures.	Identifying and characterizing potential threats. Identifying technological opportunities Measuring and modelling the physical battle space environment.	Performing studies, analyses, operations research. Modelling and simulations.	Developing new knowledge. Applying subject knowledge and application knowledge to problem solving or opportunity exploitation. Developing a solid technological base for new products and services. Managing research teams with members from industry and the HES.
Seconding experienced S&T staff to advise decision makers at various levels in the DoD							
Providing training of DoD and Acquisition Agency personnel in a S&T environment							
Supporting International collaboration							

The Scientific vs. the Systems Engineering Processes in Defence R&D

As previously defined, **Science** refers to knowledge of the laws and characteristics of the natural world. The process that drives the generation of this knowledge is known as the Scientific Process and is depicted in Figure 3.

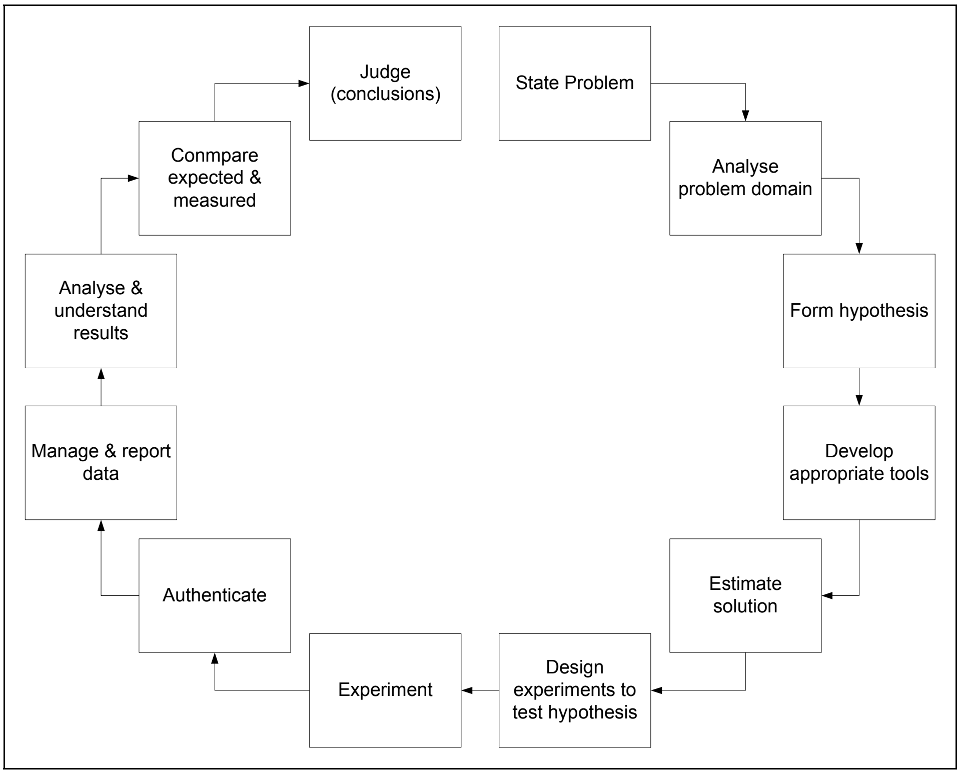

Figure 3. The scientific process[7]

Technology refers to knowledge employed to design, build, test and use manmade systems, processes or techniques. The process that drives the application of this knowledge is the Systems Engineering Process as depicted in Figure 4. This process is applied iteratively throughout the life cycle of a product/system as depicted in Figure 5**.** The systems engineering process has also been documented widely in a variety of standards (ISO 15288, EIA 632, IEEE 1220 to name a few) in one or other form. The basic elements depicted in Figure 4 are however present in all of them.

Both the scientific and the systems engineering processes are in fact basic problem solving approaches that are utilized in the execution of the DERI roles as defined in Table 1.

In the R&D role the SE process is totally applicable. In the Smart Buyer, Smart User and Smart Decision Maker roles, knowledge of the systems engineering process is essential to understand the context in which the support is required (e.g. Requirements definition, Design Reviews, DT&E, OT&E, etc.). Knowledge of the tools and techniques required in engineering of complex systems are also essential.

[7] Dr Jan Roodt, *DERI Modelling and Simulation Verification, Validation and Accreditation Process*, DEFT-MSADS-00049 Rev 1, June 2001

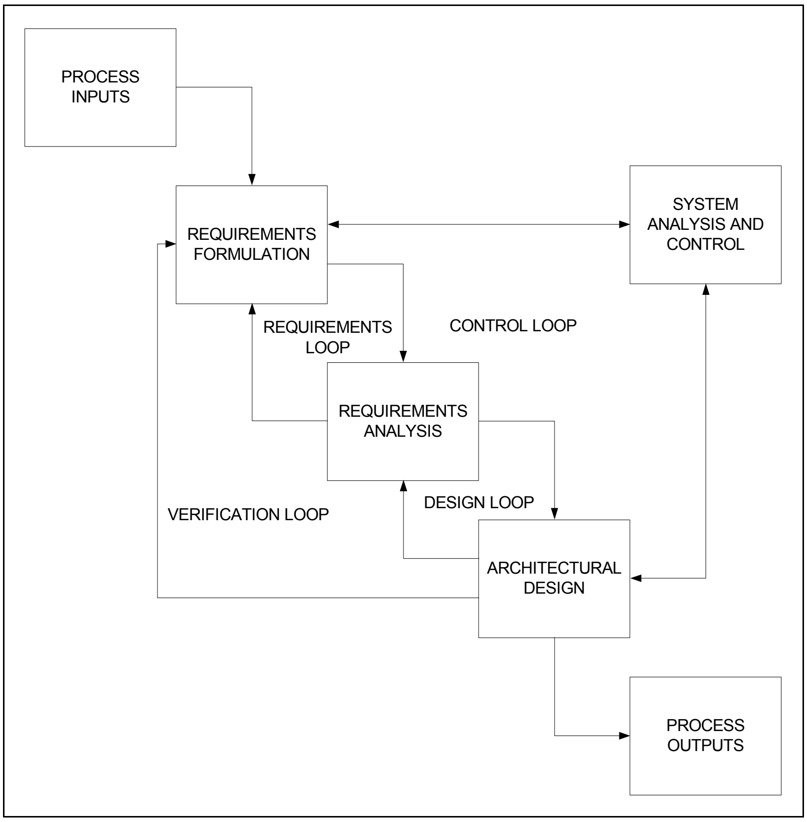

Figure 4. The systems engineering process[8]

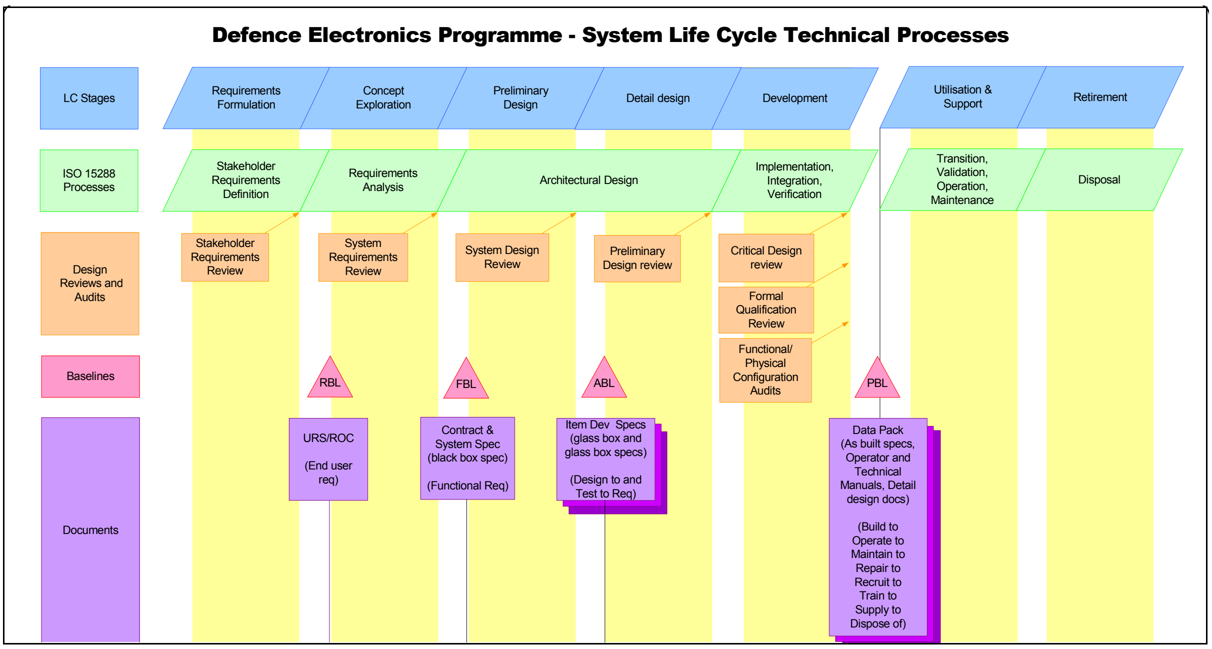

Figure 5. An example of a typical life cycle

[8] INCOSE, "Systems Engineering Handbook", Version 1.0

Tailoring the SE process for application in defence R&D

The SE process (Figure 4) as well as the life cycle model (Figure 5) is in particular prone to inappropriate application. SE activities are often performed only because some standard defines it as part of the process. Quite often the experience and knowledge does not exist to understand why certain activities are required and what the implications will be if it is omitted or applied less vigorously.

The golden word in the application of the SE process is and always has been **TAILORING**. The context and required outcome of a project plays a major role in the tailoring of the processes and activities required. Most standards like ISO 15288 provide guidance on tailoring.

When properly implemented, systems engineering will:[9]

- Provide a structured process for integrating and linking requirements, schedule, decision milestones, and verification – it works best when the project team is committed to the systems engineering process.
- Enable the project team to work to a single, integrated set of requirements and processes
- Enable integration of the system at the requirements and design stages (before sunk costs) rather than waiting until hardware and software is available
- Reduce unplanned and costly reengineering necessary to resolve omissions and integration difficulties

The systems engineering process in isolation is however not a sure recipe for success. Good project management principles and processes are equally important to ensure the success of any project. This is indeed acknowledged in modern process standards like EIA 632: Processes for engineering a system (refer to Figure 6), and ISO/IEC 15288: Life cycle management – System Life Cycle Processes (refer to Figure 7).

[9] From INCOSE website - http://www.incose.org/lib/aiaa/brochure.html

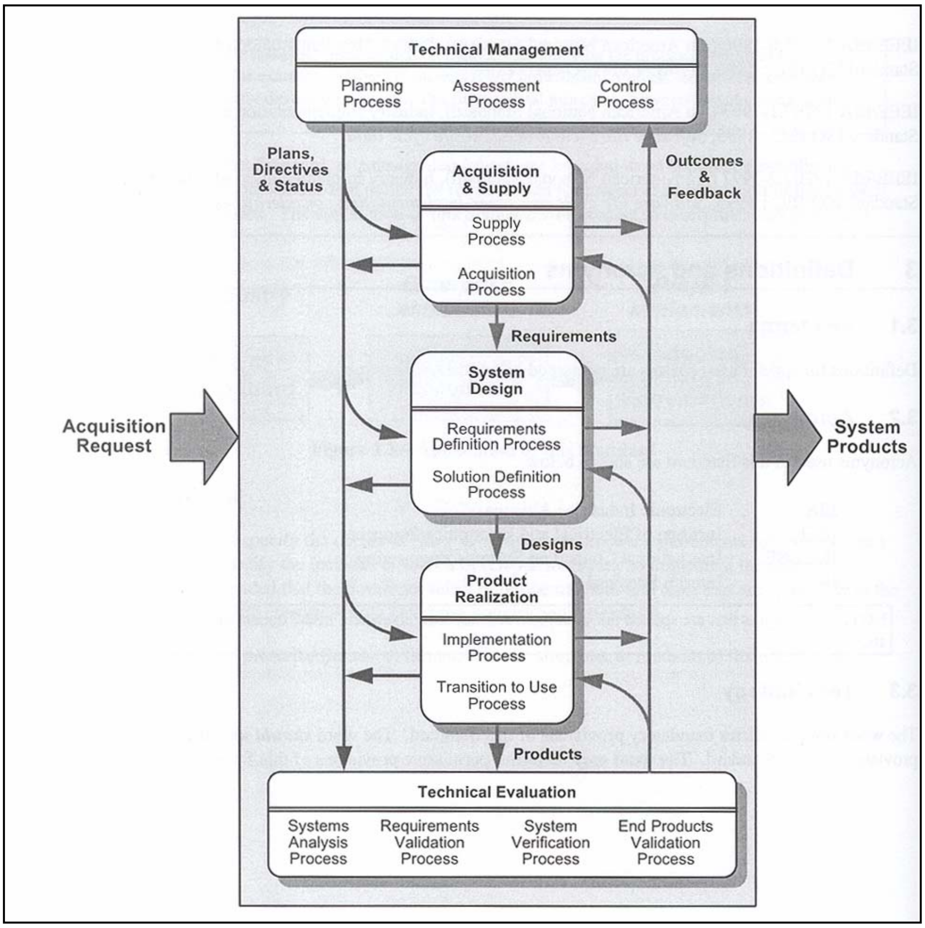

Figure 6 EIA-632 processes for engineering a system

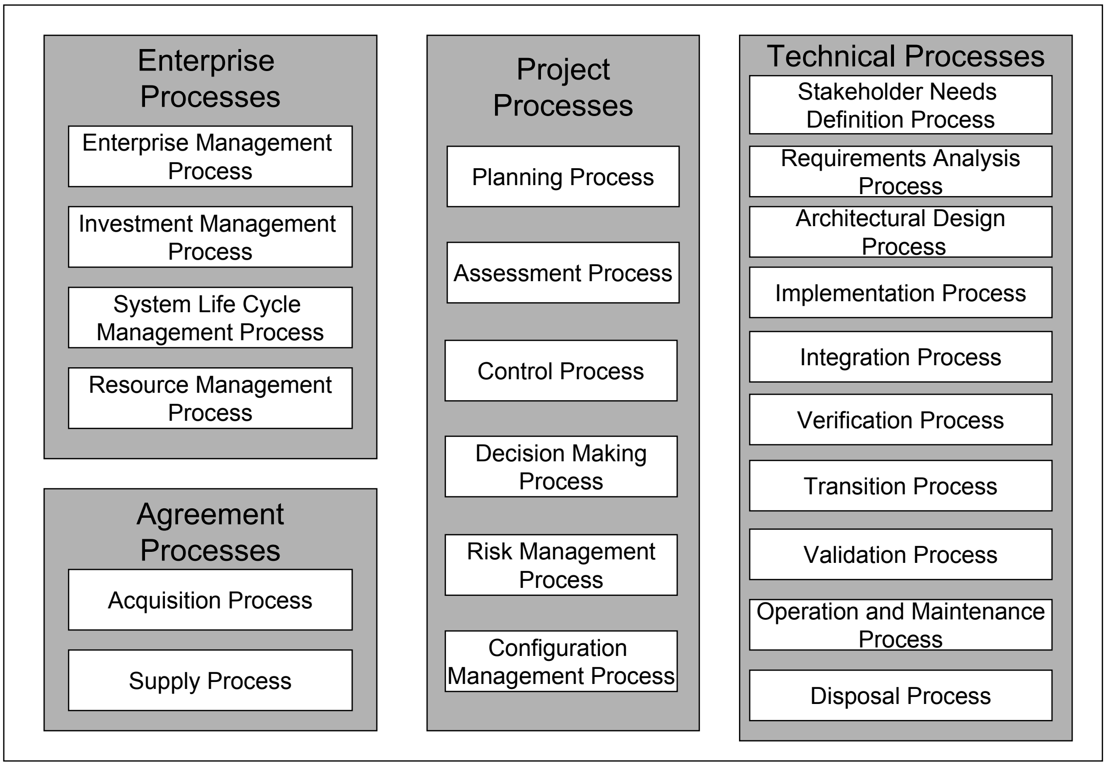

Figure 7 ISO/IEC 15288 system life cycle processes

Conclusion

In accordance with the definition of the DERIs and the scope of their proposed activities as defined in the White Paper on the South African Defence Related Industries and the White Paper on Science and Technology, both the scientific and systems engineering process are very applicable in the modern DERI. It is however very important that in the application of the processes, the proper tailoring to the scope and level of the job at hand must be considered.

Processes provide a structured approach to analyse difficult problems and engineer complex systems while increasing the repeatability and quality of the work. Indiscriminate application of processes may however lead to unnecessary work being performed with resultant high project cost and not necessarily any contribution to the improvement of the quality of the work.

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Biography

Francois Anderson is a CSIR Fellow and a radar specialist with 27 years of experience in radar research as well as the definition, design, manufacturing, integration and testing of radar systems. He has been instrumental in the establishment of modern millimetre wave and pulse Doppler radar technology at Defencetek and continues to be one of the leading radar engineers in South Africa and the world.

Alwyn Smit is a systems engineer at CSIR Defencetek. He has 17 years experience in project management and systems engineering in the defence industry. As the systems engineering process owner for the Defence Electronics Programme (DEP), he is responsible for the training and support necessary to facilitate the effective implementation of proper systems engineering on all DEP projects. He is also a member of the management team of the South African Chapter of INCOSE.