Framework for Systems Engineering Research

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Abstract In this paper a framework is proposed to perform systems engineering research within South Africa. It is proposed that within the reference of the National Research Foundation (NRF) classification of research, systems engineering is a Field of Specialisation that falls within the Specific Scientific Domain of Engineering, as part of the Main research Field of Operational Research. The Four categories for systems engineering research in South Africa are proposed to be: Formal Theories for Systems Engineering, Tools for Systems Engineering, Processes for Systems Engineering (Standardised behaviour) and Systems Engineering Applications.

Introduction

Research consists of a whole continuum of research designs that cover a spectrum from the soft science to that of the hard sciences (Marais 2012).

On the one end of the continuum are hard sciences, like engineering and physicals sciences. The research design for this is fairly easy and straightforward. An experiment is designed based on some mathematical model, the parameters to be kept constant are defined and the ones that need to be varied are done under controlled conditions. The observations are documented and the model is either accepted or rejected based on the empirical measurements. The research design is that of logic positivism.

On the other end of the continuum one finds the cases where a model do not exists, all the variables are not known, or ethics prohibit the researcher to keep the parameters under control. The complexity in the design of the research is just much higher than that of the hard sciences. Parameters cannot be quantified. This is typically what one gets in the soft sciences, where measurements are made qualitatively in a specific environment. The outcome could also be that one cannot generalize any results from the research. It is only valid for that specific instance that was investigated. One also has the dilemma of the measurements that influences the environment or subject under investigation in such a way that the measurements cannot be repeated. This leads to a post-modernistic mindset in which the measurements are defined relative to the subject under investigation.

Systems Engineering Research

We already know from various researchers that it is difficult to do research in systems engineering (Rhodes & Valderi 2007) (Valderi & Davidz 2009) (Sparrius 2011). Do you follow the methods of the hard sciences or that of the soft sciences, in other words, is systems engineering a hard engineering discipline or is it a management discipline?

A popular method for doing systems engineering research is the case study, see Friedman & Sage (2004) and Tetley & John (2009) for examples. Research methods that are related to the case study method are action research (Davison, 2004), (Noffke, S. & Somekh, 2009) and design science research with all their various variants, (March & Smith 1995), (Hevner et. al, 2004), (Van Aaken, 2004), (March & Storey 2008). In the opinion of the author the various forms of design science research are nothing more than special forms of action research as confirmed by Järvinen (2007) with all the ethical problems associated with the method (Iivari, 2007). Sein et. al (2011) merge action research and design science research into action design research, but in essence it is still a special instance of action research. The problem with case study research is that problems cannot be generalized. Further, with action research, design science research and action design research the process of research is also changing or shaping the environment it is applied in (Burns 2007) which leads to major ethical questions on the method (Iivari 2007).

Sparrius (2011) proposed to follow the quasi-scientific method that uses experimental and control groups. This method is an accepted method used in the life sciences. The problem with this approach is that the methods and organization involved in the research of systems engineering make it impractical on both a financial and time dimension most of the time. There is also the ethical dimension one needs to take into account when you choose experimental and control groups, as one deals with humans in complex situations, because a measurement or observation may alter the environment or the humans under study.

The research design in general is dependent on what the researcher wants to investigate to answer the scientific question and the associated questions. Systems engineering has many facets and to choose only one type of research design is naïve and problematic. A necessity for hybrid research methods in systems engineering exists (Rhodes & Valderi 2007). Valderi & Davidz (2009) states that empirical research in systems engineering is a new frontier with many challenges that includes:

- Conducting the empirical research in the field.
- Threats to validity associated with data collection.
- Considering empirical mixed-methods research.

It is the author’s decision, based on experience and need, to divide the systems engineering research effort into the following areas:

- Applications
- Methodologies and Tools
- Systems Engineering Management
- Theoretical Fundamentals

This can be visualized as shown in Figure 1.

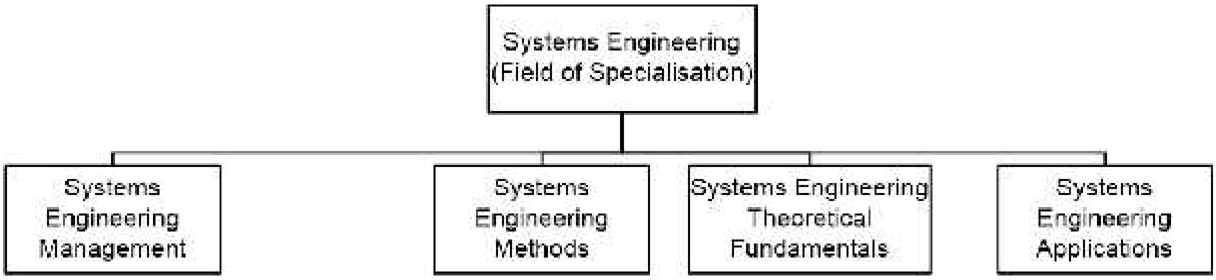

Figure 1: Systems Engineering Research Areas

Research on Applications

The research of systems engineering applications in various fields are probably the most reported type of research at the INCOSE SA Research track. The researcher uses the systems engineering process and other standards like IEEE Std 1220 or ISO 15288 or a formal model such as SEMBASE (Erasmus & Doeben-Henisch 2011) as a reference. It can be augmented by the systems engineering capability maturity (SECM) EIA 731 or similar models like the capability maturity model integrated (CMMI). Through various research instruments, the level of systems engineering compliance to these reference models is measured in a company or industry. Examples of research on systems engineering applications in South Africa are:

- Systems Engineering Benefits for BAE Land Systems OMC Vehicles (Mgoza 2011) (Mgoza & Erasmus 2012)
- Evaluating the Systems Engineering Management Model used by Denel Land Systems: A Case Study (Nyareli 2012) (Nyareli & Erasmus 2013a, 2013b)
- The effect of configuration management in the operation of engineered systems (Mootane 2012) (Mootane & Erasmus 2013)

Methodologies and tools

Research into methodologies and tools are into various techniques and methods that can help the systems engineer in performing his work better. The tools and techniques should not be confused with software applications that may support some of these methodologies and tools. One example from this research area is the very popular effort in Model Based Systems Engineering (MBSE). Research is done on methods and tools that can support any of the eleven roles of a systems engineer (Sheard 1996):

- Requirements Owner
- System Designer
- System Analyst
- Validation/Verification Engineer
- Logistics/Operations Engineer
- Glue among subsystems
- Customer interface
- Technical manager
- Information Manager
- Process engineer
- Coordinator

Examples of research on systems engineering methods and tools could be:

- Functional Failure Identification in the Design of a Nuclear Power Plant (Erasmus 2009)
- Proposal for a Standardized Functional Architecture for Use in Plant Systems Engineering (Erasmus, Lotz & Botha)

The above two articles do not report on research investigations. The two proposed methods can be investigated in a scientific framework in various ways. One method that can be successfully used for problem solving is through action research (implying also design science research or action design research) that allows for a baseline description before the methods were applied and then a reflection on the results after the method has been introduced.

Systems Engineering Management

Systems Engineering Management consists of the three broad categories discussed by Defense Acquisition University (2001), namely, the Systems Engineering Process (SEP), Development Phasing and Life Cycle Integration. In general it deals with processes that is nothing more than standardized behavior of humans. This is the area where most engineers first get their feet wet with systems engineering. Unfortunately, this is also the area that is used for justifying why systems engineering should not be used on a project. A lot of the work currently being done in the area of systems engineering management is around standards, how it should be organized and their development. Unfortunately, the Cargo Cult Science phenomenon (Feynman, 1974)(Sparrius, 2011) is prevalent in this area and future research needs to produce evidence for successes and failures.

The author did not do any formal research in this area yet, but past publications on work in this area are:

- Semiotic Modelling of a Software Development Company (Erasmus, Doeben-Henisch, & Muir 1999)
- The PBMR Integrated Process for Engineering (PIPE) (Erasmus 2004)
- Application of IEEE Std 1220 and ISO 15288 in the development of a Systems Engineering Master Schedule for the PBMR Project to Satisfy Nuclear Regulatory Requirements (Erasmus 2005)
- Experiences in using agile methods for software engineering (Erasmus 2005)
- The Pebble Bed Modular Reactor and the Usage of Systems Engineering to Establish New Standards for the Nuclear Revival (Theron, Matzner & Erasmus 2007)

Various research designs can be used to investigate the above topics for scientific research purposes as discussed by Valderi & Davidz (2009).

Theoretical Fundamentals

In South Africa, the research on the theoretical fundamentals of Systems Engineering is a neglected activity. This area is very abstract and this could be the reason for the low activity in this area, especially amongst systems engineers who are pragmatists and want to get things done. Unfortunately, for an engineering field to be taken seriously amongst other engineering disciplines, it must have a solid theoretical basis that underpins the system engineering methods and processes as valid and consistent (Valedri & Davidz, 2007).

Simpson & Simpson (2010) give a non-extensive summary of formal theoretical work in Systems Engineering as a special branch of general systems theory. The main activities in this area are to reflect on the other areas of research and abstract a formal theory for systems engineering from the results in the various other research areas. The formal models are then tested in the other areas for applicability. In this research area the following examples of research work using structuralist philosophy of science (Balzer et. al, 1987) are:

- Interdisciplinary Engineering of Intelligent Systems. Some Methodological Issues (Doeben-Henisch, Bauer-Wersing, Erasmus, Schrader & Wagner)
- A Theory for the Systems Engineering Process (Erasmus & Doeben-Henisch 2011)
- A Theory for Systems Engineering Management (Erasmus & Doeben-Henisch 2011)

Classification of Systems Engineering Research

An academic research programme for systems engineering in South Africa that performs the above areas of research needs a classification in terms of the National Research Foundation's (NRF) framework for evaluating research output. The NRF accredits academic researchers based on their research output. In establishing systems engineering as an academic research field in South Africa, the question is how to define systems engineering research in the NRF's framework for evaluating research output. Systems engineering entails interdisciplinary cooperation, but one should not confuse this interdisciplinary nature with the scientific specialization demanded in the NRF framework. The researcher had personal interviews with several researchers in the area of industrial engineering and engineering management research. A possible research classification for systems engineering research work seems to be as follows: The scientific domain is engineering, the main research field is operational research and the field of specialization is systems engineering, as shown in Figure 2.

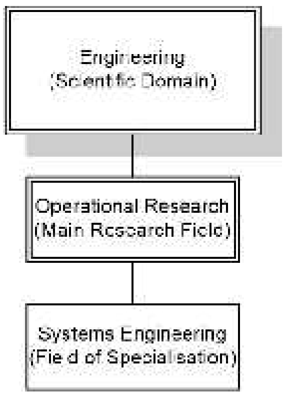

Figure 2: Classification of Systems Engineering Research in terms of the NRF framework

Conclusion

In conclusion, systems engineering can be a specialization field within the NRF framework for scientific work. Systems engineering is a field of specialisation within the operational research main research field that forms part of the engineering scientific domain.

It is proposed that systems engineering has four areas of research: application, methods/tools, systems engineering management (standardized behavior) and theoretical fundamentals.

Systems engineering is both an engineering and management discipline (INCOSE 2007). Thus, the whole spectrum of scientific research designs (hybrid research methods in systems engineering (Rhodes & Valderi, 2007)) must be appropriately applied to uncover the scientific truth underpinning systems engineering.

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Biography

Louwrence Erasmus worked for 20 years in academia, national and international industries on multi-disciplinary projects. He is a registered professional engineer with ECSA and a senior member of IEEE and SAIEE. He serves on the management committee of INCOSE South Africa. He is an advisory board member of Third Circle Asset Management. He received the B.Sc., B.Eng., and M.Sc. degrees from the PU for CHE and the Ph.D. degree in 2008 from the NWU. He is a Principle Systems Engineer at the CSIR since 2013.