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A Case Study of Systems Engineering Implementation in Designing Electronic Blast Systems

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Abstract. It is not known if a lack of formal system engineering processes being used in the design and development of new and existing systems, lead to high risk of failure in the implementation of electronic blast systems. In mining, more specifically electronic blast systems, minimal research exists on the application of system engineering principles and practices to deliver better systems faster, and more cost-effectively compared to that of ad-hoc, non-systemic approaches. The main objective of the research was to determine how well system engineering processes are applied in electronic blast systems implementation. The investigations showed results of the measurement through the SECM model's and revealed that the company is on maturity level of 2 with aspects of level 3 in all three focus-area categories, namely technical, management and environment. The activities performed indicate that SECM outputs are managed to a plan, and there are some defined organisation processes used to plan and execute activities. System engineering processes do exist but are informal, and most are not measured, and this prevents process improvement, and hence an increase SECM maturity level.

Introduction

South Africa is one of the world leaders in mining, more specifically in production and reserves of minerals and metals. The current South African mining environment is not short of engineering challenges, particularly in electronic initiation (blasting) systems. Mining operations inherently are large and complex systems which contain geological risk, uncertainty and variability Holton and Porter (2012). Blanchard (2008) affirms that in general system complexity is on the increase, mining systems inclusive, which results in newfound challenges with the creation of these newer systems. New technologies and systems being driven in mining operations have resulted in the increased life cycles of mining systems, while the technology lifecycles are diminishing. The influence of new technology systems being pushed in the gold and platinum mining sectors Holton and Porter (2012) is continually changing the requirements of mining operations. Proportionately, life-cycle costs of these systems in this advancing technology landscape is also increasing Blanchard (2008).

Due to lower commodity prices, there is a global drive for the efficiency of mining systems, including electronic initiation systems to make mining more financially viable. Systems engineering and management principles are the emerging paradigm in project environments to transform the governance from "project based" to "system based" and increase the chance of holistic success in multiple industries including mining Locatelli et al. (2014). (Lemberger and Erasmus, 2014; Sharon et al., 2011) argue that system engineering processes are entrenched within the development process, and organisations utilise the systems engineering without identifying as such because of a combination of ignorance and obscurity existing between the domains of project management, system engineering management. Challenges of improving efficiency in mining and more specifically electronic initiation system has benefited and can benefit further from further use of system engineering principles Holton and Porter (2012).

Research Objective

Modern day electronic blast systems used in mining operations needs to meet the needs of the customer and must be inherently safe, robust, reliable, supportable, of high quality, cost-effective over total life-cycle of the product. It is not known if a lack of formal system engineering processes being used in the design and development of new and existing systems, lead to high risk of failure in the implementation of electronic blast systems.

The preliminary investigation suggests that there is a lack of formal system engineering processes being used in the design and development of new systems and existing systems. This is a shortcoming in system design and development due to lack of proper initial planning and development of user requirements with a system engineering approach and consideration of the total lifecycle of the systems. Risks are not fully assessed in the beginning, top down, and over time there is an exponential increase in lifecycle costs in our modern-day resource constrained environment, with a high risk of failure in the implementation of mining systems.

This case study attempts to answer the following question: How well is systems engineering methods implemented in an organisation that designs and implements electronic blast system with regards to the system engineering process and system engineering management?

By answering the above research question, the main objective of the research is to determine how well system engineering processes are applied in electronic blast systems implementation.

Conceptual Method

This case study determines how well system engineering and management principles are applied in the successful implementation of mining blast systems. The development, advancement and utilisation of the innovative technologies are resulting in complex electronic initiation systems technology which (Kortnik and Bratun, 2010; Singh, 2000):

- require extensive training to acquaint the user;
- are more expensive than alternate pyrotechnic systems,
- have a higher risk of malfunction due to system complexity; and
- require higher levels of safety than superseded.

Whyte (2016) provides a brief literature analysis on current approaches, models and frameworks used to evaluate the implementation success of electronic blast systems, as well as system engineering perspectives. The theme across literature is that the application of system engineering principles and practices delivers better systems faster, and more cost-effectively than ad-hoc, non-systemic (Cook, 2000; Holton and Porter, 2012). Considering the system engineering perspective, the success of a system is a result of following the system engineering process throughout its life-cycles, viewing all of its components on a totally integrated basis, using a top-down, bottom-up integrated approach Blanchard (2008). The two commonly used dimensions of performance are efficiency and effectiveness, where effectiveness refers to doing the right things, the right time, with the right quality or the extent to which customer requirements, while efficiency is doing things right, expressed as a ratio between expected and actual resource consumption a measure of how economically the firm's resources are utilized when providing a given level of customer satisfaction (Neely et al., 2005; Sink and Tuttle, 1989). Using engineering and system engineering, IDEF0 framework, (Fanta and Erasmus, 2014; O'Donnell and Duffy, 2002) define efficiency as a measure ratio of the difference between the output and input of a system, and resources consumed by this activity and effectiveness is how the output of the activity meets the goal of the activity.

The System Engineering Capability Model (SECM) is structured to support a wide variety of improvement activities and is used in this research study as a conceptual model to analyse the output of electronic blast systems implementation GEIA (2001). Stemming from organisation definition of goal and objectives, essential system engineering and management tasks needed for success, were identified and included in the SECM model Blanchard (2008). The SECM model, contains three Focus-Area Categories, Technical, Management and Environment GEIA (2001). Each Category represents a grouping of Focus Areas, which contain a set of related, unique practices that address a particular aspect of systems engineering GEIA (2001). The Technical Focus Areas Category contains technical aspects of the system engineering disciple GEIA (2001). The Management Focus Areas Category support the Technical Focus Areas Category through planning control and information management, which promotes efficiency, cost-effectiveness, and execution of system engineering process which the marketplace demands according to (GEIA, 2001; Barber, 1998; INCOSE, 1996).

Integrating the capability levels and the SECM conceptual framework the three SECM categories and focus can be evaluated using the capability levels. The capability measure is applied to measure the status of the electronic blast system implementation process. There are six levels of system engineering capability from lowest level is Level 0-lnitial, to highest level of Level 5-optimizing (which is the optimal level of performance), and are defined based on observed plateaus of organisational performance achieved as they strive for improvement in business processes and system engineering related activities GEIA (2001).

The successful development and management of systems requires both maturity and capabilities that span across a combination of areas such as systems engineering, processes, procedures, methodologies and tools expanding a multitude of system engineering process areas Lemberger and Erasmus (2014). Measurement of process and organisations capability through SECM results in a measure of system efficiency. An integer number represents each level that is supported by a description of specific practices that are desired to meet the requirement of that level. A decimal number of 4.6 indicates a maturity level of 4 and 60% of specific practices for level 5.

Research Methodology

A descriptive case study using one company will be used to describe the maturity of this company is in terms of SECM. The research was conducted at a single selected player within the electronic blast system field, and the company will remain. The research study assumes that people within the electronic blast system industry, at different levels of the organization, have a limited and vary degrees of understanding of general system engineering and management principles is an important one, because it implies that collecting of data cannot be achieved effectively using standardized instruments alone which are based on system engineering concepts and processes. Additionally, the researcher will be required to translate respondent's responses into categories, focus areas, and themes in system engineering and management principles. The qualitative and quantitative data is collected using semi-structured narrative inquiries and public documents, the data analysis triangulation will include narrative qualitative, and statistical quantitative data analyses. The triangulation/mixed method research approach as seen in Figure 1 below, is used in this research study and will increase the ability to interpret both qualitative and non-experimental quantitative findings to be administered (Creswell, 2013; Thurmond, 2001). An accidental or incidental sample is utilised as this is the most convenient collection of members of the population that are near and readily available for research purposes, due to the competitive and secretive nature of the industry only one company could be readily available for research purposes (Welman et al., 2012). The unit of analysis for this study is the single company's engineering processes.

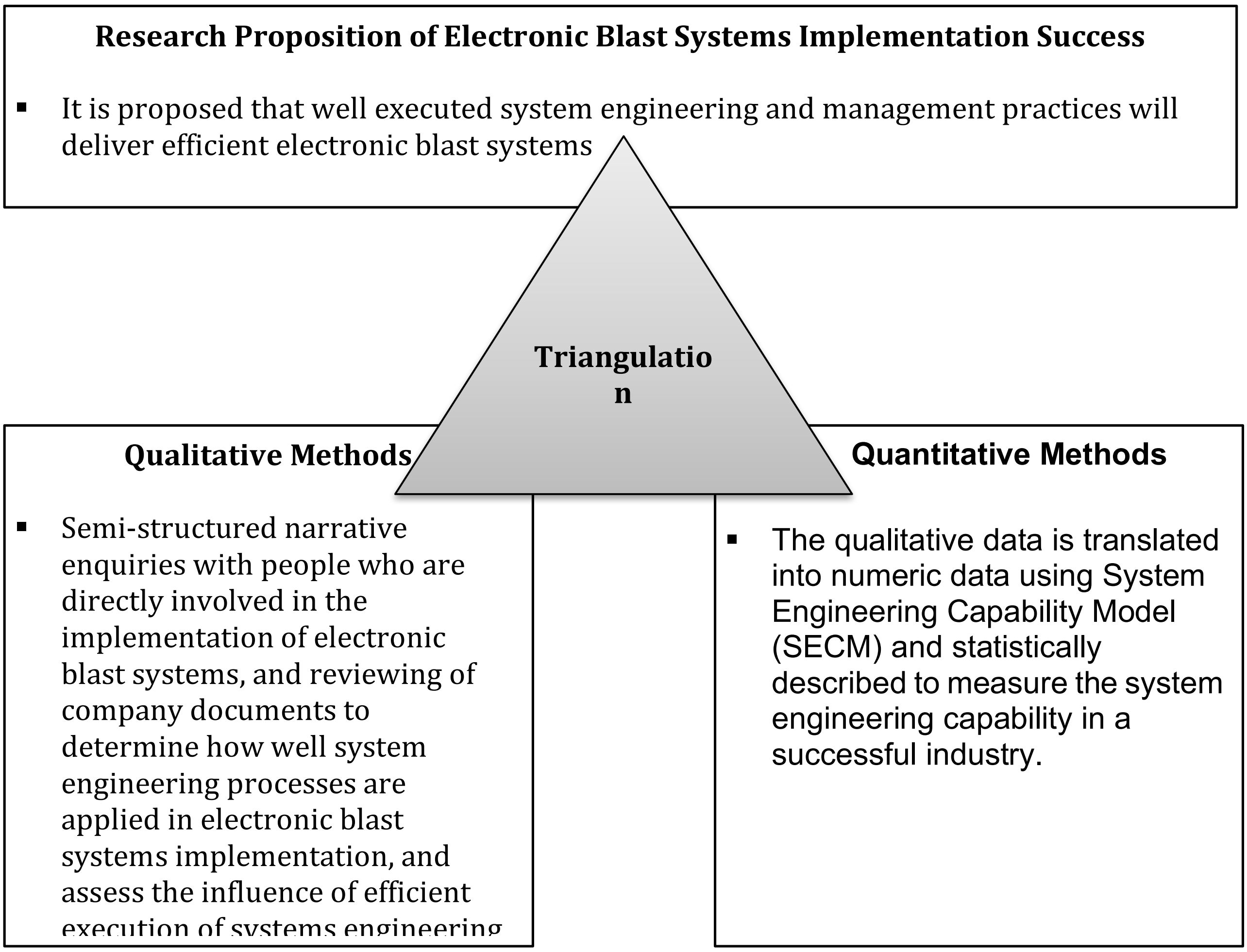

Figure 1. Research Approach for the Investigation

Results

The results of the investigation are discussed along the lines of the research objective and research propositions reported following the SECM categories and focus areas. The descriptive statistics showing the demographics of respondents is tabulated in Table below.

This case study answers to what extend the system engineering process and system engineering management concept are performed in the implementation process. This is done through analysis of interviews for common themes in system engineering process and system engineering management practices through the SECM model's three focus-area categories, technical, management and environment.

Table 1. Descriptive Statistics of Research Study

	Total Sample
Respondents	11
Gender*(% male)*	90,9%
Departments *(*includes executive, marketing, production, project management, hardware, firmware and software)*	7
Engineering Experience*(average years)*	16,8
Electronic Blast Systems Experience*(average years)*	9,9
Electronic Blast Systems Experience*(maximum years)*	20
Electronic Blast Systems Experience*(minimum years)*	3
System Engineering Level*(%beginner)*	27,3%
System Engineering Level*(%intermediate)*	45,5%
System Engineering Level*(%advanced)*	18,2%
System Engineering Experience*(average years)*	7,1
Electronic Blast System Projects*(average number)*	8,4
Electronic Blast System Projects*(median)*	6

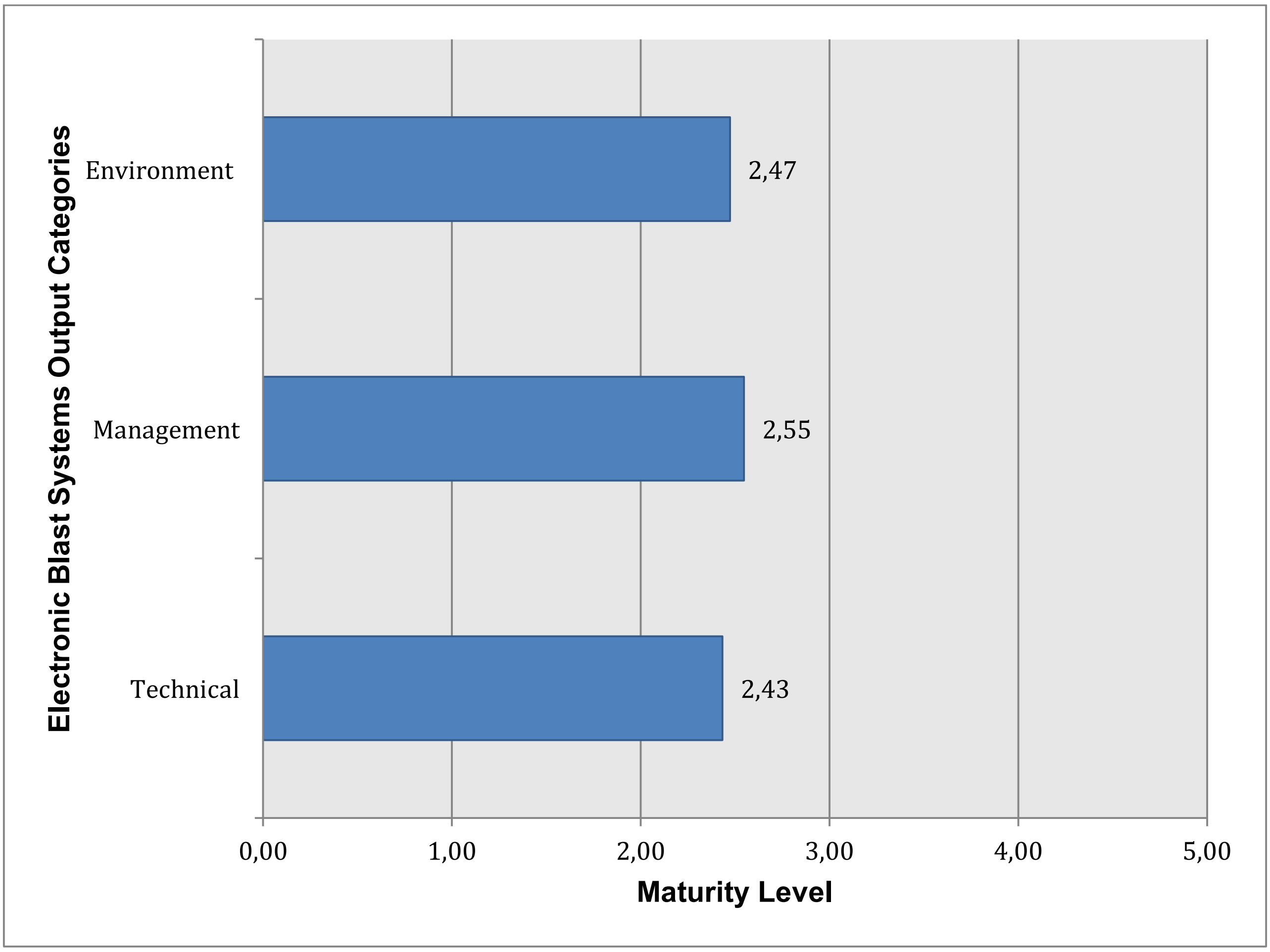

Figure 2. Respondents Results to the of Electronic Blast Systems Output Categories

The respondents' results of the measurement through the SECM model's reveal that the company is on maturity level of 2 with aspects of level 3, where activities performed indicate that SECM outputs are managed to a plan, and there are some defined organisation processes used to plan and execute activities. These results are depicted in Figure 2 above.

Technical Outputs

Technical focus-areas category FA 1.1 – 1.7 results seen in Figure 3 depicts that the company is utilising system engineering processes and management, and are managed to plan. The company has a defined organisation process used to plan and execute the defined solution activity, and data is collected and analysed to improve the activity. The define solution activity ranked high in maturity level. The respondents indicated that requirements were obtained however it was hard to obtain due to the organisational structure, inability to deconflict stakeholder's requirements and contrasting stakeholder discussions held at multiple levels in the organisation with varying styles. System engineering processes do exist but some are informal, and many respondents argued that the small size of the company did not warrant the formal system engineering processes. When focus areas such as system validation contained personnel with a single specific purpose, the activities are more formalised. Structured decision-making techniques are not implemented successfully, and the company does this informally with no document capture. The company's limited documentation and processes prevent process measurement and process improvement and hence increase maturity level. Although performed, there was no formal way for integration activities and verification. Respondents still agree that there is room for improvement in engineering processes.

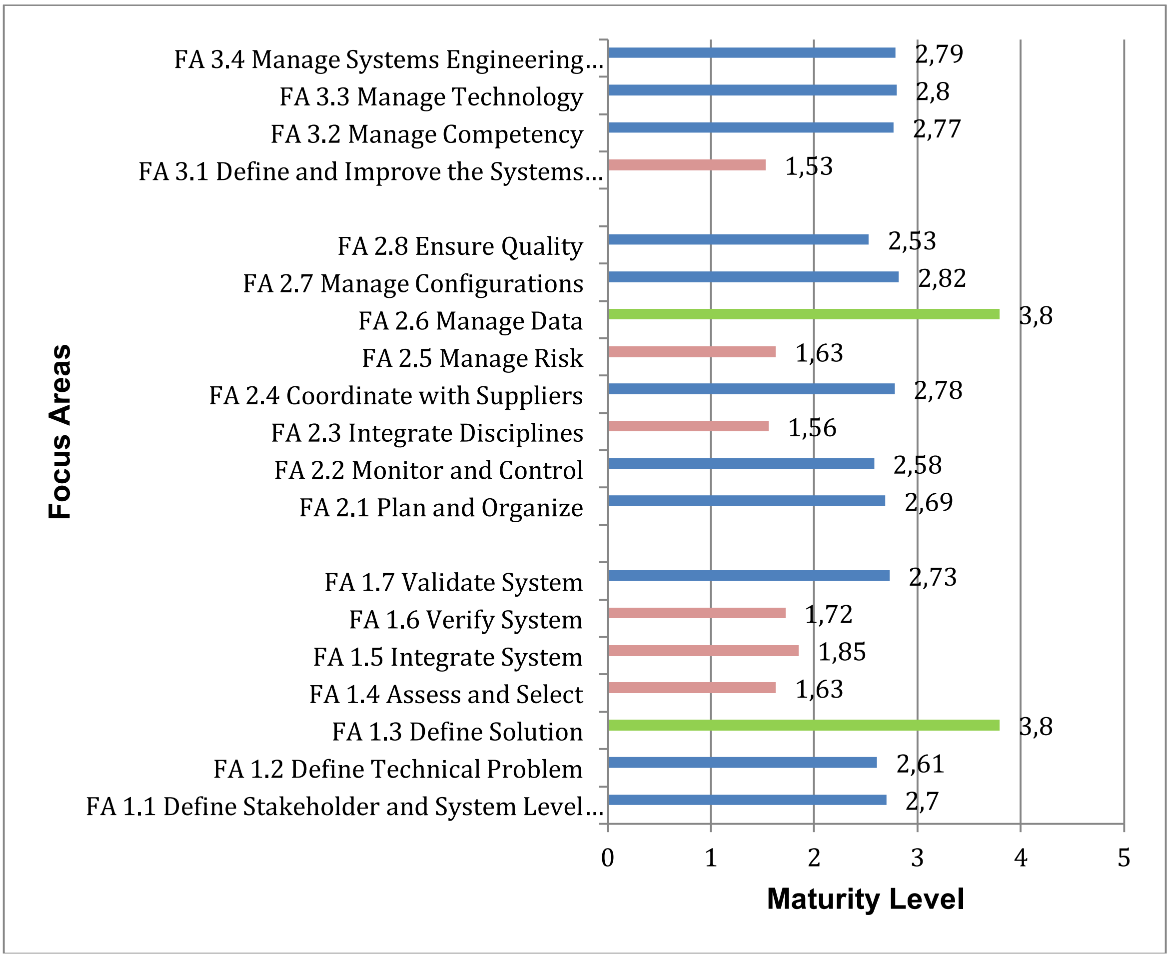

Figure 3. Respondents Results to the of Electronic Blast Systems Output Focus Areas

Management Outputs

Management focus-areas category FA 2.1 – 2.8 results seen in Figure 3 depicts that the company is utilising system engineering processes and management, and are managed to plan. The company has a defined organisation process used to plan and execute the data management activity, and data is collected and analysed to improve the activity. The data management activity ranked high in maturity level. The organisation examines the re-use of select technologies and available, Commercial-Off-The-Shelf (COTS) technologies but respondents comment that they do not it enough due to safety concerns, since it becomes difficult to prove safety on COTS. The respondent admits that the company is at risk of being a follower and not a market leader, and management is the barrier to changing this paradigm. The respondents commented that critical resources are identified, but contingency plans were not put in place or acted upon. Respondents commented that technical approached were design to meet demand in general, and get it out the door and explained a barrier to following engineering processes to realise a system correctly. Respondents further comment that projects are divided into primary and secondary projects and that the primary projects being major strategic projects were monitored more than the secondary projects. Reviews of technical performance are achieved through steering committee meetings with senior company executives where there is the management of changing priorities, important decisions, and prioritising of projects. Respondents admit that there are no project audits, and hence no experiential learning from history.

Environment Outputs

Environment focus-areas category FA 3.1 – 3.4 results seen in Figure 3 depicts that the company is utilising system engineering processes and management, and are managed to plan. The company has a defined organisation process used to plan and execute the data management activity, and data is collected and analysed to improve the activity. The respondents agree that the company contains engineering processes obtained from best practices, but not all are enforced. Respondents also observe a lack of a full life-cycle approach. On organisational infrastructure support, respondents comment that this is lacking and it is a cause for pressure and time constraints in the process. Respondents admit that required tools are available and they attend more personal training than being aligned to projects or company work.

Conclusions and recommendations

The theme across literature is that the application of system engineering principles and practices delivers better systems faster, and more cost-effectively than ad-hoc, non-systemic approaches (Cook, 2000; Holton and Porter, 2012). However in mining, more specifically electronic blast systems, there was no research to prove if the theme held true, and so there was no reason to suspect system engineering processes and management being used. Researchers observed that the challenges faced by aerospace and military are similar to the new frontier challenges of deep-level mining, but there was minimal research to determine the status of system engineering in mining, and more specifically electronic blast systems (Cook, 2000; Holton and Porter, 2012). What was known was that the success of an electronic blast systems could be a result of following the system engineering process throughout its life-cycles, viewing all of its components on a totally integrated basis, using a top-down, bottom-up integrated approach Blanchard (2008).

The main objective of the research was to determine how well system engineering processes are applied in electronic blast systems implementation.

The investigation shows that the results of the measurement through the SECM model's reveal that the company is on maturity level of 2 with aspects of level 3 on all three focus-area categories, namely technical, management and environment. The activities performed indicate that SECM outputs are managed to a plan, and there are defined organisation processes used to plan and execute activities. System engineering processes do exist but are informal, and most are not measured, and this prevents process improvement, and hence an increase SECM maturity level. The investigation also revealed system engineering processes within the development process, and systems engineering processes and management were utilised without identifying as such because of a combination of ignorance and obscurity existing between the domains of project management, system engineering management (Lemberger and Erasmus, 2014; Sharon et al., 2011). Challenges of improving efficiency in mining and more specifically electronic initiation system has benefited and can benefit further from further use of system engineering principles (Holton and Porter, 2012).

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Biography

Aldaine Whyte has over six years of experience in engineering design, focusing on cutting edge technology and innovation. He has worked as part of a large engineering team, in the research and development of the South Africa's military capabilities in the field of RADAR and electronic warfare. Currently, as a design engineer for AECI-Detnet South Africa, he is involved with innovative solutions and development of electronic initiation systems in the mining industry. Aldaine holds a BSc Honors degree in Engineering from University of Kwa-Zulu Natal, and has a Masters degree in engineering management from the Graduate School of Technology Management at the University of Pretoria.

Louwrence Erasmus worked for more than 20 years on multi-disciplinary projects in academia, South African and international industries. He is a senior lecturer in the Postgraduate School of Engineering Management at the University of Johannesburg. He is a Principal Systems Engineer at the CSIR since 2013. He is a research associate at the Graduate School of Technology Management at the University of Pretoria. 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 was awarded a PhD degree in 2008 from North West University, Potchefstroom. He is a registered professional engineer with ECSA and 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.