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Systems Engineering Management Process Maturity of South African Manufacturing Organisations

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Abstract--**The National Planning Commission's National Development Plan: Vision for 2030 (NDP) aims to promote economic equality by focussing on innovation within key sectors of the economy. It has been noted that systems engineering has the ability to integrate people, processes and technologies to deliver innovative complex systems. The investigation set out to improve the understanding of systems engineering (SE) with focus on organisations in manufacturing of coke, petroleum, chemical products, rubber or plastic products as it represents the largest income and employment provider in the manufacturing sector in South Africa. Ten process areas were identified to measure systems engineering management (SEM) activities using a Capability Maturity Model (CMM). Data gathering was conducted using a combination of face-to-face and telephonic interviews of six (6) randomly selected organisations in the identified population using a six level Likert Scale. Overall SEM process maturity measured 2.91, indicating a general lack of formal SE procedures.**

I. INTRODUCTION

Oerlemans & Pretorius [16] states that "Innovation is the driving force of economic development and the competitiveness of its firm," with technology both deepening and hastening the world's interconnectedness [15]. Increased global system interconnectedness presents both benefits and challenges in being able to effectively compete in the global marketplace. Competing in this global market requires a combination of innovation, integration and management of complex systems, resulting in an increase in system complexity and associated risks [15].

Competing in this global market requires a combination of innovation, integration and management of complex systems, resulting in an increase in system complexity and associated risks for the successful development and management of new complex systems [15]. Oerlemans & Pretorius [16] reiterates that the adoption of a National System of Innovation requires organisations to develop and manage additional complex systems, while still being able to meet customer specifications, project schedule and budget constraints.

Current global economic conditions and drivers of change, such as political and technological dynamics, require organisations to innovate and effectively manage increasingly complex systems. The rate at which system change and interdependence is occurring is risking the ability to understand and predict complex system behaviour. "Exploiting systems engineering's associated tools and techniques are critical to manage future complex systems" [11].

The National Planning Commission's National Development Plan: Vision for 2030 relies on the existence of South African organisational capabilities to meet these global challenges. The goal is to create an environment for sustainable employment opportunities and economic growth by focussing on sectors described in the New Growth Path [15]. The plan builds on the South African governments New Growth Path as an inclusive process for the elimination of poverty and inequality, through targeted microeconomic reforms in key areas of the South African economy including the manufacturing sector [18]. Accomplishing the goals, as set in the plan, requires focus on the development and expansion of a "robust, entrepreneurial and innovative economy", to achieve a sustainable and inclusive development for South Africa [15].

Systems engineering processes are vital, within any organisation, for the development and implementation of successful complex systems [2], [6], [10]. Systems engineering has the ability to integrate people, processes and technologies to deliver innovative complex systems [11].

Evaluating current systems engineering capabilities and process maturity in South African manufacturing organisations is critical, to ascertain organisational capabilities in the development of innovative complex systems, to achieve the goals set in the National Development Plan. Effective evaluation requires an analysis of formal systems engineering theory, the use of systems engineering management tools, applications and effective methods to measure process capability and maturity. Ultimately, leading to improved systems design, applicable to any organisational application, in any sector of the economy.

A. Systems Engineering in South Africa

Systems engineering is a method that relies on systemics, a view of studying systems from a holistic view, as well as system vision. Chapurlat [2] defines systems engineering as a collection of concepts and relations between concepts and processes that aim to efficiently and accurately produce a system of interest (SOI).

Systems engineering (SE) processes are entrenched within the development process, the maturation of these processes, especially within South African organisations is yet to be quantified. According to Honour & Valerdi [10] and Kossiakoff [12] this is as a result of a combination of ignorance and the obscurity existing between the domains of project management, systems engineering management and terminologies utilised in organisations.

Increased system complexity requires a complete understanding of current systems engineering practices, as well as research into the relationship between SE theory and SE applications. The successful creation and management of complex systems requires both maturity and capabilities of a combination of systems engineering processes, procedures, methodologies and tools expanding a multitude of SE process areas [1], [3], [5], [12]. Based on work by Erasmus & Doeben-Henisch [7], SE can be constructed to include four branches, namely: Formal theory, Systems Engineering Management (SEM), SE tools and the applications used for SE, shown in Fig. 1 below. This allows for the identification and correlation between underlying theory and real world applications, as distinct systems engineering areas can be focused upon.

Many organisations utilise systems engineering without identifying it as such, due to ignorance and the obscurity existing between the domains of project management, systems engineering management and terminologies utilised in organisations. This divergence stems from the general lack in understanding the benefits of systems engineering existing within organisations as well as the availability of multiple Systems Engineering standards [10, 12].

As noted in the introduction, the National Development Plan and the New Growth Path focus on key sectors of the economy that are seen as pivotal in the eradication of inequality and the growth of the economy towards the vision for 2030. The new growth path outlines the sectors that require focus for the economy and the goals within each sector. The Economic Development Plan focusses on the tools, legislation and economic environment that government is required to create to realise these goals.

The deeper level of integration that exists in the world economy has been “accompanied by uncertainty and volatility” [15]. The commission understands that for a country to develop, it is required to improve their ability to innovate and by investing in critical areas. Examples of such programmes are the space programme (United States), high tech manufacturing (Singapore) and almost everything in China. These countries as well as their companies, “constantly benchmark, monitor, evaluate and adjust” [15]. The processes mentioned above are indicative of mature process within these organisations and thus is a key point that must be noted as part of this study within the sectors presented above.

B. Objective of the paper

Organisational process maturity is related to the organisations ability to effectively develop and manage complex systems, both product and process, throughout its entire life-cycle. Preliminary research illustrates a lack of knowledge regarding current systems engineering process capability and maturity levels in South African manufacturing organisations. Additionally, a lack of formal systems theory makes the implementation and development of systems engineering principles difficult, as systems engineering currently relies on application and experience for the creation of new methods and techniques. A clear measurement of current systems engineering processes and capabilities in the identified sectors within the National Development Plan is required to ensure an alignment of goals and expectations. Based on the above observations, the following research question is proposed:

- What are the maturity / capability levels of Systems Engineering processes in South African organisations?
- Are there correlations between maturities of Systems Engineering Management processes and organisational size?

II. CONCEPTUAL FRAMEWORK FOR THE INVESTIGATION

Lemberger [13] provides a comprehensive literature analysis of SE theory, SEM and Capability Maturity Models (CMM). Analysis of the literature highlights that SE is a multifaceted discipline that requires key activities and capability maturity for effective management and function; the human factor is important in the formulation of systems theory, such that human factors and engineers are the primary actors in systems theory; and CMMs have been widely utilised to measure process area maturity.

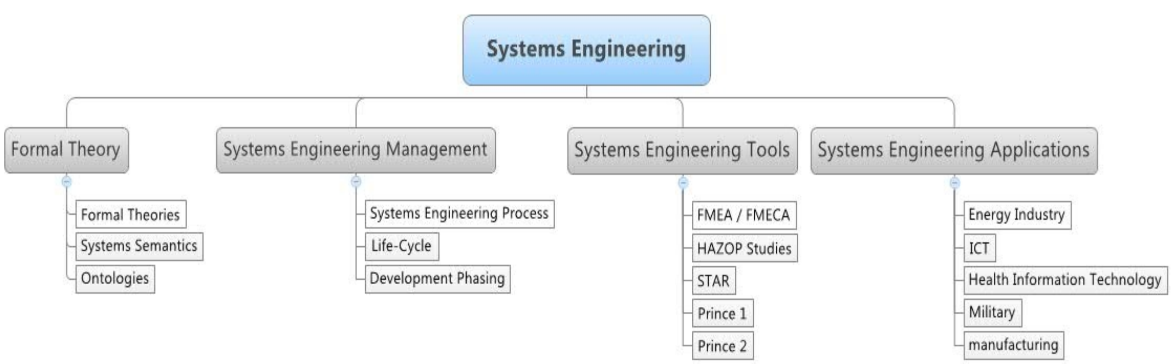

Fig.1. Branches of systems engineering based on Erasmus [13]

Erasmus & Doeben-Henisch [9] presented a visualisation of the interaction between the three activities identified for effective SEM practices. The authors concluded that a true depiction of SEM, required interaction between the activities. The activities are described as [5]:

- Development phasing which controls the system design process and defines baselines for coordinating the subsystems, disciplines and specialties design efforts. This is a result of the structured approach where defined limits are created and interfaces between systems defined.
- Systems engineering is a dual process whereby it defines a structure for solving any design problem, as well as the tracking and monitoring of requirements through the design effort.
- Life cycle integration involves the customer and direct stakeholders in the design process, ensuring viability of the developed system for a sustainable life cycle. Thus the incorporation of the entire life cycle in the process creates a more balanced and thorough system.

Elm & Goldenson [6], through a collaboration between the National Defense Industrial Association Systems Engineering Division (NDIA-SED, the Institute of Electrical and Electronic Engineers Aerospace and Electronic Systems Society (IEEE-AESS) and the Software Engineering Institute (SEI) of Carnegie Mellon conducted a study to identify links between systems engineering best practices and project performance. The study expanded on previous research by the authors, of U.S defense contractors, to include non-defense projects and non U.S System developers.

Utilising a Likert scale such that 4 represent very good practices and 1 very poor practices, the study focussed on measuring the Systems Engineering Capability of Systems Engineering activities within identified organisations. A total of 148 respondents, mainly from the U.S defense industry, was utilised for the tabulation of results, with the authors noting that the absence of available benchmarks made the generalisation of results difficult and the suggested covariation of relationships used to draw useful conculsions. The study utilised v1.1 of the CMMI, and generated eleven measures of SE capability, relating to management and technical groups as the basis of the study. The 11 process groups are presented below [6]:

- Requirements Development and Management
- Project Planning
- Product Architecture
- Trade Studies
- Product Integration
- Verification
- Validation
- Project Monitoring and Control
- Risk Management
- Configuration Management
- Integrated Product Team Based Capability

The proposed framework utilised in this study involves using formal SEM theory and a CMM to measure SEM process maturity in South African manufacturing organisations, shown in shown in Fig. 2.

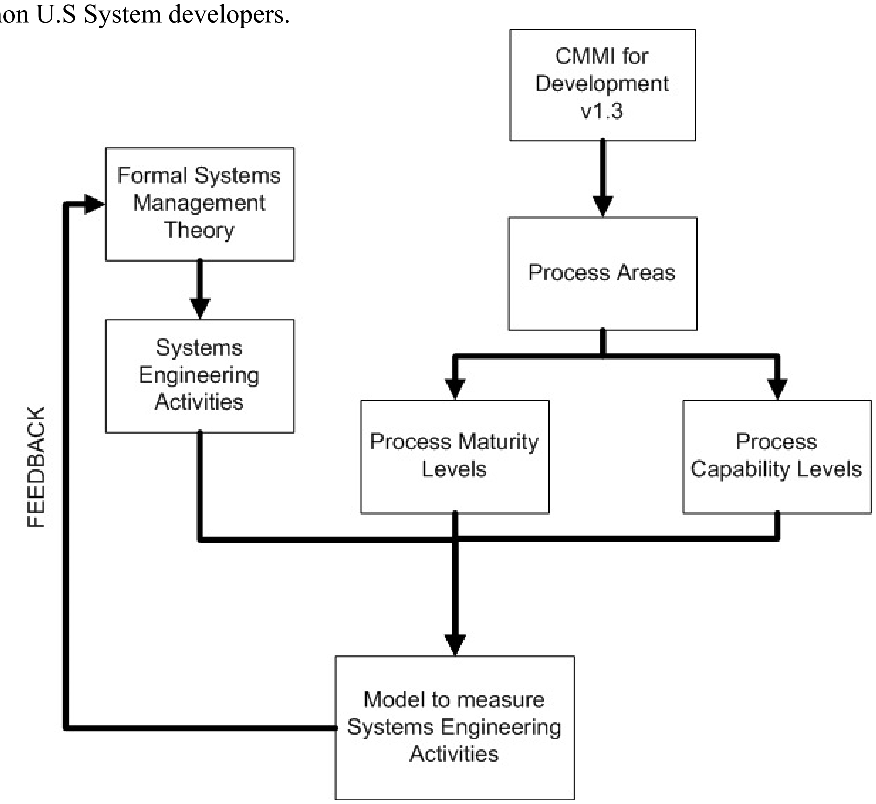

Fig. 2. Conceptual methodology utilised in the investigation [13]

Using Elm & Goldenson 6] as a baseline, process areas are associated to SEM theory suggested by Erasmus & Doeben-Henisch [9], by comparing process area specific goals, defined by the CMMI for Development v1.3 [3]. Each process area is then measured and its associated SEM activity maturity quantified.

Ten process areas in this investigation were identified are based on; its presence for one of the three key SEM activities, as well as being measured process areas in [6]'s study. Fig. 3 illustrates the association between SEM activity and CMM process areas as used in the study. Each process area is present in multiple activities, suggested by [9], although the method and strategy for its implementation is unique to the activity. Each process area has specific and generic goals described in the CMMI Model for Development v1.3 [3]

- Specific Goals: A required model component that describes the unique characteristics that must be present to satisfy the process area.
- Generic Goals: A required model component that describes characteristics that must be present to institutionalize processes that implement a process area.

III. RESEARCH METHODOLOGY

Liberson (1992 as cited in [14]) states that in social sciences 'it is unrealistic to assume that all relevant data will be consistent with a theory even if the theory is correct.' This is due to the complexity, diversity and changing social phenomenon, making the existence of competing hypotheses often fortuitous in the management research area. Williams [20] emphasises that the research process is systematic in the definition of an objective, managing data and its effective communication. These results occur within pre-established design frameworks that must meet existing guidelines, such that repeatability and confidence in the findings exist.

Addressing the study objectives, the sample population (qualitative) and data correlation (quantitative) methods were combined. The sample population consisted of six (6) randomly selected manufacturers of coke, petroleum, chemical products, rubber or plastic as it represented the largest income portion (29%) within the manufacturing sector [19]. Six (6) interviews were conducted through a combination of telephonic (2) and face-to-face (4) interviews, with interviewees including:

- Chief Technical Officer (CTO)
- Operations Executive
- Project Manager
- Production Managers
- Product Manager

A questionnaire was completed through either face-to-face or telephonic interviews. Each interviewee was chosen based on their operational knowledge of their respective organization, with each providing invaluable insight into the function of each process area addressed within the study including:

- Background information and project example
- Process areas
- Additional Information

The questionnaire was designed to obtain data required to test the propositions and research questions. This was achieved by attributing each question in the questionnaire to the proposed proposition / research question. Each organization was analyzed separately with data analysis including the calculation of means and standard deviations of measured process areas. Overall process area maturity results were calculated using the mean of each measured SEM activity of interviewed organizations.

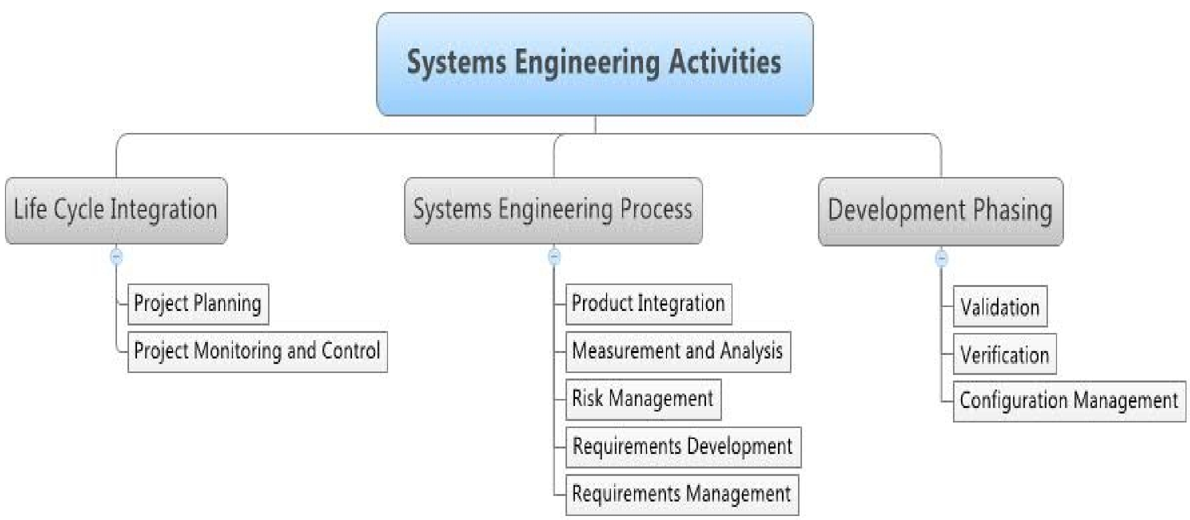

Fig. 3. Process areas related to SEM activities [13]

TABLE 1. STUDY LIKERT SCALE AND DEFINED LEVELS FOR MATURITY MEASUREMENTS [13]

Maturity Level	Defining Characteristic
Not Performed (Level 0)	Organization starting point. The process / capability does not exist
Initial (Level 1)	No formal requirements are present and no formal system definition exists
Repeatable (Level 2)	A basic system life cycle is defined and is recreated to all projects
Defined (Level 3)	The entire system life cycle is documented, standardized as process for project development. The process can be tailored to suite an individual project.
Managed (Level 4)	Detailed measures of the process and product quality are collected. Both the process and products are quantitatively understood and controlled. This entails involving all aspects of the life cycle.
Optimizing (Level 5)	Continuous process improvement is enabled by quantitative feedback from the process and from innovative ideas and technologies in the life cycle.

Fig. 4. Research question methodology

Questions were designed to solicit information regarding the extent to which organizations process areas meet the specific goals defined by the CMM. Each process area was quantitatively scored, using a linear 6 level Likert scale, shown in Table 1.

Testing of the conceptual model was conducted by asking questions regarding a recent project performance and comparing the difficulties experienced during the project to the relevant capability / maturity level associated with the study, shown in Fig. 4 below. Scaling of results to match the scale used by [6], allows for comparison between the study's results and implementation of a CMM.

Fig. 5 illustrates the questionnaire's design for the quantitative measurement of both process maturity and organisational size used to test Proposition P_1:

- Proposition (P_1): Systems Engineering Management process maturity is related to organisational size
- Null Proposition (P_0): Systems Engineering Management process maturity is not related to organisational size

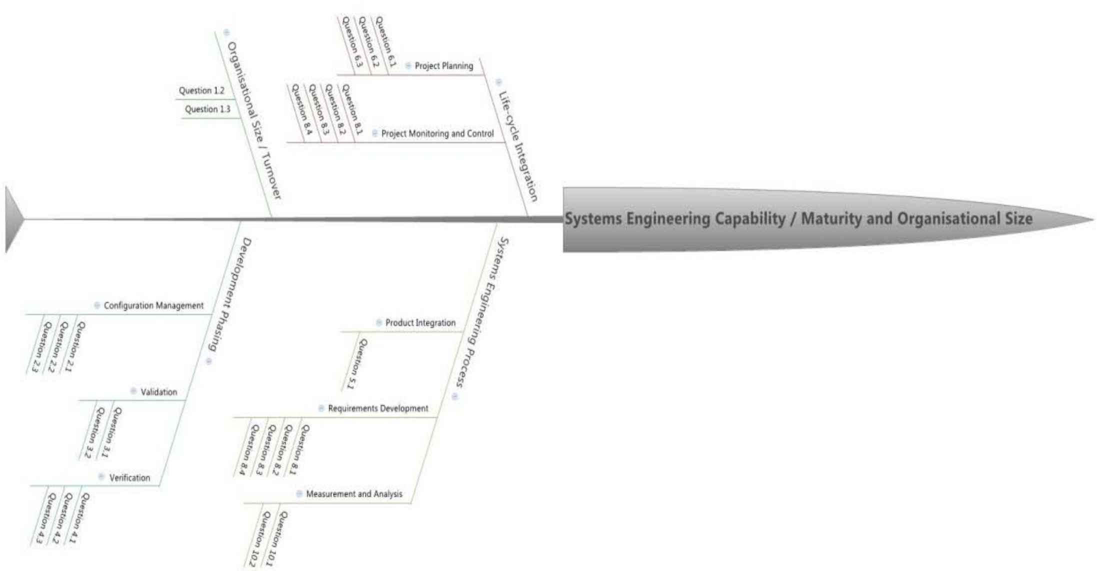

Fig. 5. Proposition P_1 data gathering technique [13]

Based upon the interviewee's responses statistical analysis using a t-sample test was used to determine the correlation between; organisational size and the overall SEM process maturity. A t-sample test is used on small sample sizes by utilising sample means and standard deviations of two sample sets to test the correlation.

IV. RESULTS

Principal results regarding systems engineering process maturity levels as measured in the sample population of South African Manufacturing organisations are presented. Results are discussed in line with the proposed research questions and proposition discussed in section I.

A. Process area capability / maturity

The effectiveness and validity of the model is based on:

- The inclusion of the final two conducted interviews resulted in a 5% change in the measured process areas, indicating a convergence of data. Data convergence improves the studies validity as an increase in the population has a small effect on the measurement of process area maturity when assuming a normal distribution of process maturity.
- Interviewees identified the same process areas as the source of project issues as were measured as the least mature process areas, as discussed later in this chapter.

Fig. 6 presents measured process area maturity as a result of the data gathering process. As shown in Fig.6, Validation (3.58) and Risk Management (3.33) were measured as the most mature process area, with Measurement and analysis (2.33) and Project Monitoring and Control (2.46) measured to be the least mature process areas.

Validation ensures that the product or system meets the requirements for its intended use when placed in its intended environment. Validation is a critical process is for any organisations, as it influences almost all other process areas while ensuring system quality. Almost all respondents indicated that the validation was a critical aspect of their organisations, with several respondents noting that they are required to meet strict system requirements as a result of both legislative and contractual requirements.

Risk Management entails the preparation, identification and mitigation of both identified and unidentifed risks in a system. Effective risk management minimises potential losses as well as aids in effectient system development and execution.

It is important to note that although mutiple questions regarding Risk Management were conducted, only a single question was used to measure process maturity as questioning focusses on the same specific process area goals. The result is that a standard deviation of 1.21 was measured, indicating a large spead in the sample population. This may affect the measure process area maturity; however the majority of organisations clearly indicated that risk is an important aspect of the operation, with existing procedures constantly evaluated, monitored and updated accordingly at regular intervals. Organisations claimed to possess mature risk management processes, but the presence of considerablly immature process areas within these organisations have not been identified as risk areas. Questions arise concerning the effectiveness of organizations risk management processes relating to the scope which the risk management capability encapsulates.

Measurement and Analysis (Trade Studies) is concerned with selection criteria for the best system solution. Several organisations possessed clearly defined and documented processes with appropriate rating scales and benchmarks used to select between alternative solutions. Organisations without formal Measurement and Analysis procedures indicated this was a result of the organisation being customer requirements driven. These organisations rely on the customer to provide solutions and not the organisation driving the process of system solution.

Project monitoring and control was the second worst performing process area. All interviewees indicated that the process area was not a quantitatively measured process / procedure. This indicates a process area in its infancy, the result is that organisations lack the ability to maintain and complete projects.

B. Systems engineering management capability maturity

Overall measured SEM activity is shown in Table 2. The measured SEM activity maturity for each interviewed organization is presented with overall SEM activity maturity measured as a mean of the combination of the three SEM activities.

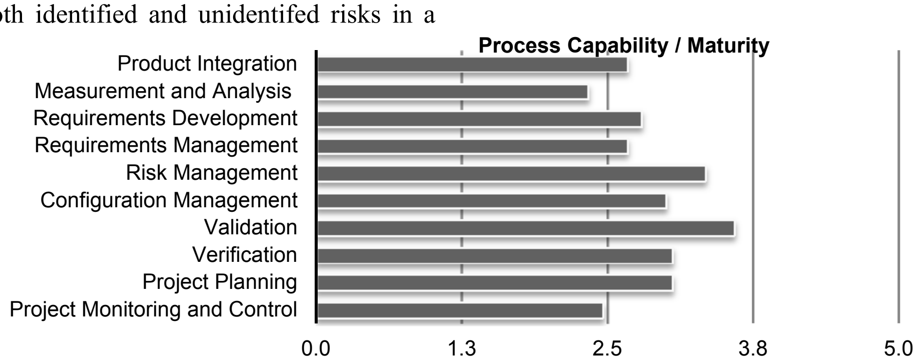

Fig. 6. Measured process area maturity

TABLE 2. MEASURED SEM MATURITY AND ORGANIZATIONAL SIZE

	Organization						
SEM ACTIVITY	1	2	3	4	5	6	Overall
Systems Engineering Process	3.55	2.95	1.70	3.20	2.25	2.90	2.76
Development Phasing	4.22	3.11	1.78	3.78	3.00	3.39	3.21
Life-cycle integration	3.92	2.33	1.25	2.83	2.92	3.29	2.76
Overall SEM maturity	3.90	2.80	1.58	3.27	2.72	3.19	2.91
Organizational Size	120	240	48	90	1300	400	

Results from Table 2 indicate that:

- SEM activities are not equally mature process areas within the interviewed sample population.
- Development Phasing is the most mature of the three SEM activities, measuring 3.21. The Systems Engineering Process (2.76) and Life-cycle Integration (2.76) management activities are not mature activities.
- Measured SEM activity of the sample was 2.91, indicating a general lack for formal procedures present within the sample organizations.
- SEM activity maturity varies between the interviewed organizations

The measured SEM activity maturities are expected. Development phasing activity maturity is expected due to high process maturity of associated process areas: configuration management, validation and verification shown in Fig. 6. Measurement and analysis and Project Monitoring and control, associated with the Systems Engineering Process and Life-cycle Integration activities respectively, were measured as the two least mature process areas. The result is that these immature process areas reduce the overall activity maturity. Varied results between interviewed organizations may be a result of the diversity of interviewed organizations representing different sub-sectors of the manufacturing sector.

It is important to note that the inclusion of the final two conducted interviews resulted in a 5% change in the measured process areas, indicating a convergence of data. Data convergence improves the studies validity as an increase in the population has a small effect on the measurement of process area maturity when assuming a normal distribution of maturity.

C. Testing of Proposition P1

Testing of the proposition required the measurement of process maturity and organisation size of the sample population, shown in Table 3.

The P_1 proposition is:

- Proposition (P_1): Systems Engineering Management process maturity is related to organizational size
- Null Proposition (P_0): Systems Engineering Management process maturity is not related to organizational size

The Null Proposition (P0) was tested using a t-sample test for gathered data (presented in Table 2). This was conducted by statistically comparing, each organizational size (Variable 1) and Measured SEM activity maturity (Variable 2) from Table 4 with results of the t-sample test (Table 3).

TABLE 3. PROPOSITION P1 T-SAMPLE TEST RESULTS

	Variable 1	Variable 2
Mean	366.33	2.91
Variance	225440.67	0.60
Observations	6.00	6.00
Hypothesized Mean Difference	0.00	
df	5.00	
t Stat	1.88	
P(T<=t) one-tail	0.06	
t Critical one-tail	2.02	
P(T<=t) two-tail	0.12	
t Critical two-tail	2.57	

Testing of the Null Proposition requires a comparison between t Stat and t critical two-tail, such that t Stat (1.88) < t critical (2.57) in the investigation. Thus the finding of the investigation is not significant and the Null Proposition (P_0) cannot be rejected such that:

- Systems Engineering Management process maturity is not related to organizational size

D. Project Difficulties

Interviewees were questioned regarding specific project difficulties of projects within their organization. Responses included issues of scheduling (planning), required design methodologies and requirements management. Interviewees were not limited in the number of project difficulties descriptions. The difficulties described by the interviewees were identified as being associated to process areas utilized in this study including Project Monitoring and Control, Project Planning, Requirements Management, Requirements Development and Measurement and Analysis.

Identified project difficulty areas are expected as these process areas were measured as the least mature process areas in Fig. 6.

E. Elm & Goldenson study comparison

Table 4 below, present's comparable results between this investigation and results of the study conducted in [6]. Data was scaled to match the 4 level Likert scale utilized in [6] for comparative purposes.

Comparisons of this studies results to that of [6] in Table 4, the following is identified:

1. Process maturity of organisations evaluated in this study is well below that of the research population utilised in Elm & Goldenson's study.
2. The maximum standard deviation of measured process area maturity of this study was 1.21, whereas Elm & Goldenson's study is 0.46. This indicates a relatively larger result distribution for this study as compared to Elm & Goldenson. This indicates that organisations in Elm & Goldenson's study possess almost equal SEM activity maturity of Development Phasing, Life-cycle integration and Systems Engineering Process.
3. Configuration management was the best performing process area in Elm & Goldenson's study.

The above observations present significant differences between the studies, explained by:

1. The scaling of this studies data to match that of [6] has a dramatic effect on the overall perception of process maturity of organization in this study. The use of a scale Likert scale of linear divisions, as used in this study, allowed for extended options for interviewees, thus minimizing bias and allowing for improved resolution of process maturity. This is emphasized by the Validation process area which is considered on Elm & Goldenson's [6] Likert scale to be an immature process area. As noted previously, interviewees in this study suggested that Validation was a mature process area as a result of industrial regulations and legislation "forcing" organization to perform clear, effective and efficient validation process for their products. Similarly, Validation, in [6], possessed a high process maturity of Validation, with many organizations bound by statutory and contractual obligations to perform extensive validation programs to ensure product compliance.
2. Organizations in this study operate in mature industries, such as the Fertiliser industry, whereby a mature industry does not see the benefits and requirements of systems engineering capabilities. Elm & Goldenson [6] utilised a sample population of NDIA, IEEE-AESS and INCOSE organizations. Interviewees operate in high technology environments such as the defence industry such that process maturity measurements, when focus is placed on a single industry may reduce the standard deviation of measured process areas.
3. The defence industry places extreme focus on all identified process areas as an important requirement in the development of defence products. Configuration management often forms part of contractual obligations and milestones in the defence industry and thus would require a mature process area.
4. Being members of Systems Engineering based societies; one would expect such organizations to possess internal systems engineering capabilities, illustrated by results of [6].

TABLE 4: COMPARATIVE RESULTS OF INVESTIGATION AND LITERATURE

Process Area	Adjusted maturities for comparison	Standard Deviation for study	Process Maturity for Elm & Goldenson [6]	Standard Deviations for Elm & Goldenson [6]
Product Integration	1.78	1.03	3.00	0.33
Measurement and Analysis	1.56	0.82	3.00	0.38
Risk Management	2.22	1.21	3.00	0.21
Configuration Management	2.00	0.56	3.40	0.38
Validation	2.39	1.02	3.00	0.33
Verification	2.04	1.18	3.00	0.43
Project Planning	2.04	1.14	2.98	0.46
Project Monitoring and Control	1.64	1.01	3.00	0.38

V. CONCLUSIONS AND RECOMMENDATIONS

A. Key Findings

The aim of this paper was to test systems engineering theory by defining and measuring systems engineering management maturities / capabilities of South African manufacturing organizations, while also investigating the application and management of systems engineering within organizations. Through the use of literature on systems engineering and Capability Maturity Models, the state of systems engineering management could be empirically defined.

Results of this investigation are critical to the National Development Plan: Vision for 2030 such that Systems Engineering Management process maturity is not related to organizational size; and is thus a positive outcome in the context of the plan.

As noted above, results of this study indicate the need for an improvement in organizations SEM process maturity. An improvement is required to help facilitate the achievement of the goals set in the National Development Plan: Vision for 2030. The National Planning Commission must also recognize the required process maturity improvements.

Management is the driver of process areas generic goals of acceptance and dynamism within an organization. The result is that the National Development Plan: Vision for 2030 scope must be an inclusive plan; focusing on all organizations within the economy. The use of a combination of legislation and organizational awareness will help stimulate focus in the improvement of SEM process maturity; however such legislation must be used with caution as its effects on overall organisational performance is unknown.

Results of the study cannot be transferred from the sample to the manufacturing population; however the model was able to measure SEM activity process maturity by matching process area specific goals to the requirements of associated SEM activities. Combining Systems Engineering Management theory presented by [9] and a Capability Maturity Model, measuring Systems Engineering Management maturity was possible. The ability to measure process area maturity was verified by: identified data convergence and the objective identification of project difficulties in organisations by interviewees, whereby identified process areas match those measured by the model to be the least mature process areas.

With reference to the above, results of the study illustrated key factors that influence measured process maturity that must be taken into consideration when implementing or comparing Capability Maturity Models, including:

- The unit of measurement of the CMM is a significant contributor to results. This is reiterated when comparing results of this study to that of [6]. Organisations operating in high technology industries such as the Defense industry are expected to possess similar process area maturities as compared to organisations in different sectors.
- The chosen measurement scale affects result resolution. A wider scale such as the scale utilised in this study allowed for improved process maturity resolution as compared to [6]. The choice of scale is emphasised when measuring organisations across sectors of the economy.

The measured state of Systems Engineering Management paints a picture of required improvement. Overall measured SEM maturity was 2.91, indicating a general lack of formal SEM processes in the sample population. Results indicate that SEM maturity activities require improvement. An organisations ability to develop and manage innovative complex systems will remain impossible without an improvement in Systems Engineering Management process maturity. Although development phasing was the most mature systems engineering activity the result must be managed with caution. The reliance of organisations on validation and verification processes for system acceptance will have a negative impact on the organisation. Ignoring the activities of the Systems Engineering Process and Life-cycle integration will lead to countless so “retrofitting” of systems as a result of the validation and verification process. A holistic approach effectively combining all three activities is required for effective Systems Engineering Management

The human aspect of systems engineering management is applicable when viewing indicated project difficulties. Managers are able to identify problem process areas however these process areas remain relatively immature as a process area. The generic goals associated with a Capability Maturity Model and managements view on the process is essential to the improvement and maturation of these process areas; which will eliminate project difficulties associated with these process areas. The result is that the presence of mature processes is not a performance guarentee. Questions arise concerning the effectiveness of organisations processes relating to scope such as that of Risk Management. Organisations are required to holistically implement processes and procedures with the intent of influencing the entire operation.

B. Systems Engineering Management process maturity and organisational size

The study was able to effectively test Proposition P_1 such that the Null Proposition (P_0) could not be discarded whereby Systems Engineering Management process maturity is not related to organisational size

The above proposition is critical for the success of the National Development Plan: Vision for 2030. The result is a positive outcome in the context of the plan. Management is the driver of process areas generic goals of acceptance and dynamism within an organisation. The result is that the National Development Plan: Vision for 2030 scope must be an inclusive plan; focussing on all organisations within the economy. The use of a combination of legislation and organisational awareness will help stimulate focus in the improvement of SEM process maturity; however such legislation must be used with caution as its effects on overall organisational performance is unknown. In addition, the National Planning Commission must recognise the required process maturity improvements and address these concerns holistically through interaction with industry.

C. Limitations of the research

Due to the small sample size used in the research, one cannot transfer results to the population of the manufacturing sector. The small sample size may create bias towards specific process areas as a result of the interviewed organisation skewing the results, and is thus only valid for this sample. Additional limitations arise from the additional sub-divisions within the coke, petroleum, chemical products, rubber or plastic industries as the author feels that requirements placed on different organisations such as the pharmaceutical industry will result in added variances between subcategories of the sector.

D. Further research

Increased population sample sizes will provide additional insight and interdependence of the human aspect of systems engineering, while also allowing providing statistical confidence regarding conclusions applicable to the entire population.

Additional research is required into each sub sector of the manufacturing sector, due to evident sub-sector maturity differences, emphasised by the comparison with Elm and Goldenson, whereby process maturity may be related to sub-sector division. The application of the model can be expanded by:

- Customising the Capability Maturity Model by focussing on process areas critical to the operations of an organisation, allowing an organisation to measure internal capabilities in line with strategic intent
- Using the model to baseline industries from which organisation can use for comparison with competitors.

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