Modelling Methodology for Engineering of Complex Sociotechnical Systems

Rudolph Oosthuizen
PhD student, University of Pretoria, CSIR, South Africa
roosthuizen@csir.co.za

Leon Pretorius
Professor, University of Pretoria, South Africa
Leon.Pretorius@up.ac.za

Abstract. Different Systems Engineering techniques and approaches are applied to design and develop complex sociotechnical systems for complex problems. In a complex sociotechnical system cognitive and social humans use information technology to make sense of a situation in support of decisions. The complex dynamic system elements, their interaction and, the complex environment make sociotechnical systems difficult to develop. A modelling and assessment methodology in support of the Systems Engineering process is required to understand the sociotechnical system's behaviour and underlying structure. It must capture the dynamic interaction as well as the effect of humans performing work in a complex environment. Cognitive Work Analysis and System Dynamics are two complementary approaches that can be applied in support of each other within this context.

Introduction

Development of complex Sociotechnical Systems (STS) often consist of integrating new technology into existing systems through application of Systems Engineering (SE) processes. SE uses modelling to explore structural, functional, and operational elements of the problem and solution space (Hitchins 2008). However, standard SE processes can struggle with complex STS, which exhibit dynamic behaviour as many unintended or unpredicted consequences may be experienced. The new artefact often leads to new task possibilities that evolve user requirements (Carroll & Rosson 1992).

The STS theory developed by Trist (1981) provides a framework for modelling and analysis of complex systems. STS consist of humans applying technology to perform work through a process within a social structure (organisation) towards achieving a defined objective (Bostrom & Heinen 1977, Walker et al 2009). Work can become complex due to dynamic interaction between the people themselves, between people and technology as well as between the people and the environment. Within the context of this paper, humans use information to assess a situation and devise plans to solve problems in a complex STS. These systems are used as a control measure to ensure successful implementation of plans in constrained and variable operational environment to achieve a successful mission.

The aim of this paper is to propose a modelling methodology for complex STS in support of the SE process. The two approaches used in the modelling methodology are Cognitive Work Analysis (CWA) and System Dynamics (SD). CWA is a framework to analyse the way people perform work in an organisation while taking the environmental constraints into consideration. The outputs of CWA are constructs or models that capture the structure of the problem. Functions provided by different technological elements are linked to the functional requirements of the system to achieve its purpose (Lintern 2012). However, CWA is limited in investigating the dynamic effect of decisions and policies on the system (Cummings 2006). The dynamic behaviour of the complex STS can be analysed using SD which uses the structure of the system in simulation. SD analyse the effect of feedback and delays on the operation of the system as a result of decisions based on policies (Sterman 2000).

The Design Science Research (DSR) framework will be used to implement the modelling methodology. DSR aims at creating technology for a human purpose, as opposed to natural science, which is trying to understand and define reality (March & Smith 1995). The proposed methodology will be demonstrated in a case study through modelling and analysis of the impact of a new collaboration technology on community security.

Sociotechnical Systems

The "Sociotechnical" concept refers to the interaction between "social" humans and "technical" systems (Walker et al 2008). During the 1950s the introduction of new technology to improve efficiency and productivity of organisations did not meet expectations. This led to the introduction of the sociotechnical approach that focussed on the joint optimisation of social and technical subsystems (Baxter & Sommerville 2011, Bostrom & Heinen 1977, Trist 1981). STS theory highlights the importance of social humans in the organisation instead of only relying on technical improvements to solve complex issues.

People perform work in organisations, utilising technological artefacts, to achieve economic performance and job satisfaction. Technological artefacts consist of the tools, devices, and techniques to transform inputs into outputs for economic gain, as seen in Figure 1 (Bostrom & Heinen 1977, Walker et al 2008). The social subsystem addresses structure of the organisation, encompassing authority structures and reward systems, as well as people in the organisation with their knowledge, skills, attitudes, values and needs. Being an open system, the complex environment also affects the STS. The socio and technical interaction can be non-linear as a result of unexpected, uncontrolled, unpredictable, and complex relationships. People also have the flexibility and cognitive ability to reorganise and adapt to address challenges and changes in the environment (Walker et al 2008).

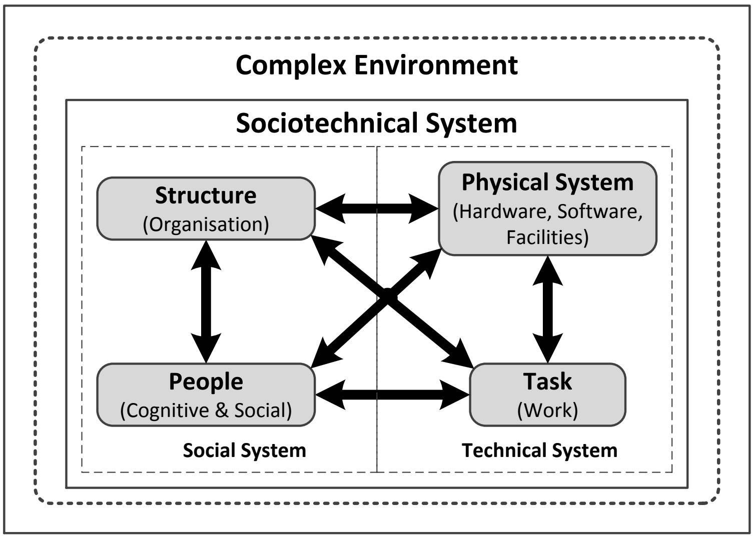

Figure 1. Sociotechnical System

Complex Systems

The term "Complex" is defined as "a whole made up of complicated or interrelated parts" which are intricately intertwined with a high level of interconnectivity (Merriam-Webster Dictionary, Gell-Mann 1994). Complex system elements have non-linear interactions (including feedback loops with delays) that cause non-deterministic, emergent, unpredictable, and unexpected behaviour. Complexity may exist in simple systems, owing to dynamic context-dependant interactions and feedback between elements. Complexity can be a characteristic of the artefact technology or its situated use in the environment. Critical tasks in complex systems tend to be time limited with decisions and actions that depend on feedback (Checkland & Scholes 1990, White 2010, Janlert & Stolterman 2010).

The causes of STS system complexity include large problem space, uncertainty, risk of hazard, social interaction, being distributed, dynamic interaction, and time pressure (Vicente 1999). The focus of the work tends to be on anomaly detection, escalation, and problem solving through cognition as opposed to routine tasks requiring a formative development approach (Baxter & Sommerville 2011, Carroll & Rosson 1992).

Behaviour as a result of human decisions and actions may not always be consistent and is dependent on the system's initial states and feedback loops. These have a high degree of uncertainty for decision makers to solve (Checkland & Poulter 2007, Baskerville *et al* 2008, Rittel & Webber 1973). Methods to analyse and design modern systems for successful operation in a complex environment need to address the social, cognitive and dynamic complexity in the system (Janlert & Stolterman 2010, Reiman & Oedewald 2007, Lintern 2012, Bahill & Gissing 1998).

Modelling in Systems Engineering

The objective of System Engineering is to solve problems by developing systems through the application of Systems Thinking (Hitchins 2008). A basic SE process starts off by distilling the needs of stakeholders, along with characteristics of the environment, to develop concepts and define requirements. SE requires modelling of system behaviour to investigate the dynamic and non-linear interaction. A model describes system structure and behaviour through abstracting reality, simplifying complexity, considering constraints, and synthesizing results.

Stand-alone systems can often not meet the requirements of complex challenges in the real world. Development of complex STS often consists of integrating different STS subsystems as well as introducing a new technology into an existing system. As a result more systems are integrated for better control and information exchange. Modern complex STS tend to be developed through piecewise replacement of subsystems with new technology. The cross-boundary interactions between non-deterministic humans and machines must be considered in this process. Integration of new technology into a complex STS cannot only rely on historic case studies and associated data for analysis, affirming the need for experiments to explore different scenarios and identifying possible counterintuitive effects (Bar-Yam 2003, Sheard & Mostashari 2009, Hitchins 2008, Papachristos 2011).

Humans use models on a daily basis to simplify and understand reality. A model is defined as an explicit and incomplete representation or idealised abstraction of reality, or selected part thereof, to aid its description and understanding. It describes the essential nature, characteristics or pattern of a thing without being the thing itself (Haskins 2010, Oliver et al 2009, Ramos et al 2012). Modelling is the act of creating models, from their conceptualization, using a standard, rigorous, structured methodology (Maria 1997). A mental model is the human interpretation of a system via his senses. Models can be used to gain control over reality in support of decisions about the world.

In SE modelling can be used throughout the system's lifecycle to describe selected aspects of structure, behaviour, operation, operation environment, enabling systems and interfacing systems. The model of the system describes how the system will change internal states as a result of external inputs. These models represent the system design and are used to communicate ideas and shared vision to other stakeholders. One output of modelling is development of a Concept of Operations (CONOPS) which provides insight into how a system will be used and implemented. This supports multiple views for theoretical or empirical understanding, calculations or predictions concerning the system without necessarily being a mimic of the system (Buede 2000, Hybertson 2009, Polack et al 2008, Haskins 2010).

Models provide cost-effective tools to generate data for analysis as well as to provide an approximation of structure and/or behaviour of the system. These are required to support better system development decisions through clarification of stakeholder requirements. The different views on the system may be organised in an architecture to structure the mode. Through understanding the stakeholder requirements, the system's requirements can be derived (Polack et al

2008, Ramos et al 2012, Maria 1997, Haskins 2010).

Modelling is based on systems thinking and forms the basis of system theory and SE. Complex systems must be abstracted and modelled at a high level to develop an architecture for lower level modes. The typical steps in a modelling process include problem identification and formulation, collect and process observed system information, formulate and develop a model, validate the model, design experiment with the model, perform simulations, analyse results, and improve the model if required. The model is constructed through schematics and network diagrams of the system to indicate how entities flow through the system (Haskins 2010, Maria 1997, Maier & Rechtin 2000).

The purpose of modelling is to gain insight into complex systems and support answering questions on the system solution or problem situation. The model should to be similar, or close approximation, to the system it represents incorporating most of its salient features. However, the model must achieve a balance between realism and simplicity to enable understanding and simulation (Maria 1997, Buede 2000, Ramos et al 2012, Polack et al 2008). Modelling of complex STS also have to capture human work in the system. Models are utilised to experiment with knowledge on the problem, test assumptions, and to develop an understanding of the implication of different solutions (Hitchins 2008, Oliver et al 2009, Stanton et al 2012).

Making absolute sense of a complex system is close to impossible as it requires a model as complex as the system itself. However, a suitable mental model to absorb and interpret information is important. Most models of complex systems are used to display general complex behaviour to support learning about the system and not to model specific, empirical complex systems quantitatively. Models can be used to attempt to grasp the structure of complex systems. Creation of a descriptive and coherent model can support deriving functional and causal relationships at the level of system behaviour. This will support an understanding of how interactions between system elements occur without having a complete understanding of the complexities and nonlinearities (Cilliers 2002, Sterman 1994, Maier & Rechtin 2000).

Modelling Complex Sociotechnical Systems

This section proposes a modelling approach to support understanding the effect a new technology will have on the human work in the system. The two modelling frameworks to be included in the methodology include CWA and SD. However, a modelling and analysis framework is firstly required to guide the integration of the modelling approaches into an effective process.

Design Science Research

CWA and SD are two fundamentally different methodologies, which need integration through a framework to support modelling and learning as part of the design phase in the SE process. DSR has been proposed as a framework for information system development through the creation of artefacts for a human purpose (Hevner et al 2004, Venable, 2006). The two basic activities in DSR methodologies are designing a novel and useful technological artefact for a specific purpose as well as evaluating its utility. Design is the process of creating a new artefact (construct, model, method, or instantiation) that does not already exists in nature (March & Smith 1995, Hevner 2007, Baskerville et al 2009, Simon 1996).

Artefacts are developed as part of a sequential problem solving process to gain new knowledge, as seen in Figure 2 (Peffers et al 2007). First, new problems or opportunities may be discovered through new developments in industry or operational environment. Next, knowledge on the problem is analysed to determine the objectives, functionality, and contribution of the solution artefact. The solution artefact is then created through design and development. A demonstration is required to assess the utility of the artefact before time and resources are committed to a thorough evaluation. Evaluation is conducted through simulation, experimentation, or case study. The aim is to gain knowledge and experience in application of the artefact to solve a problem. The outcomes are measured and compared to the objectives of the perceived problem state and solution values through. Within the context of this paper the artefact to be developed through the DSR framework is a model of a complex STS.

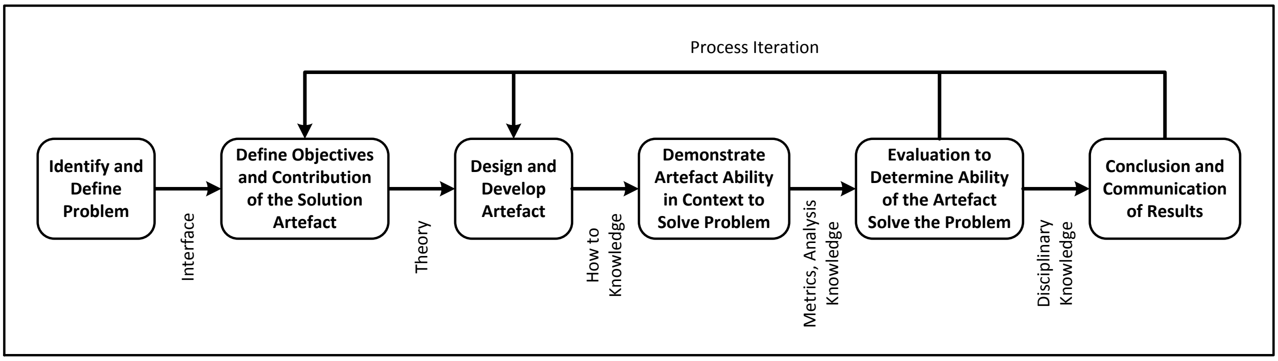

Figure 2. The General Methodology of Design Research

Cognitive Work Analysis

CWA has been applied in systems analysis, modelling, design, and evaluation of complex STS such as command and control, aviation, health care and road transport (Jenkins et al 2009). It supports the formative development of "how work can be done" instead of normative models (how the system should behave) or descriptive models (how the system is actually behaving) (Vicente 1999). The theoretical roots for CWA are in Systems Thinking, Adaptive Control Systems and Ecological Psychology.

Work is defined as an activity aimed at accomplishing something useful with a purpose, values, and success criteria. Work consists of a combination of cognitive and physical elements that interact with each other. The system must enable the human actor to perform his work effectively within the environmental constraints, with the required technology and supporting organisational structures (Lintern 2012, Naikar et al 2006). This phase of the modelling approach address the analysis of the role of a new technology in an existing complex STS. Many of the functions performed by the system evolved over time to achieve the purpose of the STS. The CWA determines how the new technology can support these functions.

The CWA process starts off with a focus on understanding the ecological elements before relating it to the cognitive capabilities of the humans to enable flexibility that helps reduce the cost of development (Vicente 1999, Bennett et al 2008). These constrains may originate in the external environment, which is in essence also a complex STS, as well as from the internal STS effects. The ecological constraints still allow for a variety of work patterns to solve unexpected problems and situations resulting in a flexible decision support. The five phases of CWA include Work Domain Analysis (WDA), Control Tasks Analysis, Strategies Analysis, Worker Competency Analysis, as well as Social Organisation and Cooperation Analysis (Bennett et al 2008, Lintern 2008, Naikar et al 2006, Vicente 1999, Jenkins et al 2009).

The WDA elicit and present information on the system from existing documentation and expert users to understand the functional structure of the enterprise and environmental effects on work. It identifies the goals and purposes of the cognitive system in a top-down approach. This is integrated with a bottom-up view of available physical resources for the human operators to achieve the purposes of the system. Since modelling is not task or event driven, many possible instantiations due to dynamic interaction between technical systems, the environment, and people are captured (Naikar et al 2006, Vicente 1999). The other phases will not be discussed in this paper.

Despite its advantages, CWA does not support developing a complete understanding of the system's dynamic behaviour. CWA constructs do not support cause-and-effect relationship analysis due to unanticipated and intentional events or the effect of time in critical environments. CWA also tends to be used for analysing existing systems instead of designing revolutionary and novel systems, motivating the need for additional tools (Cummings 2006).

System Dynamics

The concept of SD was developed to investigate the effect of feedback in social systems through Systems Thinking. The different modes of behaviour as a result of high-order nonlinear systems were related to complex problems in management and economic decision making. SD presents a method that combines qualitative modelling of complex STS with quantitative simulation (Forrester 1968, Sterman 2000, Meadows 2008, Wolstenholme 1990).

System structure is the source of system behaviour and consists of interlocking stocks, flows, and feedback loops. SD employs Causal Loop Diagrams as well as Stock and Flow Diagrams to present the process and information structure of the system for discussion between stakeholders. Causal Loop Diagram shows the causal influences between variables to identify the feedback structure of the dynamic system. Delays in feedback loops cause inertia in the system that may lead to dynamics and oscillations (Sterman 2000, Meadows 2008).

Stock and Flow Diagrams show the structures that represent the physical processes, delays and stocks that are related to the complex dynamic behaviour in the system over time. Stocks indicate the state of the system as a result of the history of changing flows to cause delays, inertia and memory. The causal connection between the stock and the flow due to decision rules result in feedback, which is important to understand the behaviour of the system (Sterman 2000, Meadows 2008). Behaviour observed over a long time leads to dynamic patterns of behaviour of the system that support learning about the underlying structure and other latent behaviours.

Complex STS Modelling Methodology

The preceding theoretical discussion the fact that successful development of complex STS depends on effective modelling and assessment that address human work with the technical system in a complex environment. The modelling methodology presented in Figure 3 integrates the theory on CWA, SD and DSR, as proposed above based on argumentative deductive logic (Rudestam & Newton 1992).

Firstly, the problem to be solved is identified and defined. This may be due to new technology available for improving a system (technology push) or from changes in environmental constraints that inhibit the effectiveness of a system (technology pull). In the second step CWA is used to present the current information on the system in relation to the operational context. Available information from documents and users are captured in constructs. An Exploratory Focus Group will be useful in capturing the views of role-players on the problem and required capabilities of a solution.

The next step is to design and develop the solution artefact, which is a model of the complex STS with the new technology. Existing and generic models of the complex STS is enhanced with information and knowledge captured in the CWA framework. The model includes constraints of the organisation and environment with a focus on how people apply the artefact to perform work towards achieving organisational objectives. The SD modelling process develops a Causal Loop Diagram and Stock and Flow Diagram. The utility of the model is demonstrated through SD simulation to understand the effect of different technologies on complex STS dynamics. The purpose of the SD is not to predict how successful the system will be, but to understand the effects of certain causes of possible system behaviour.

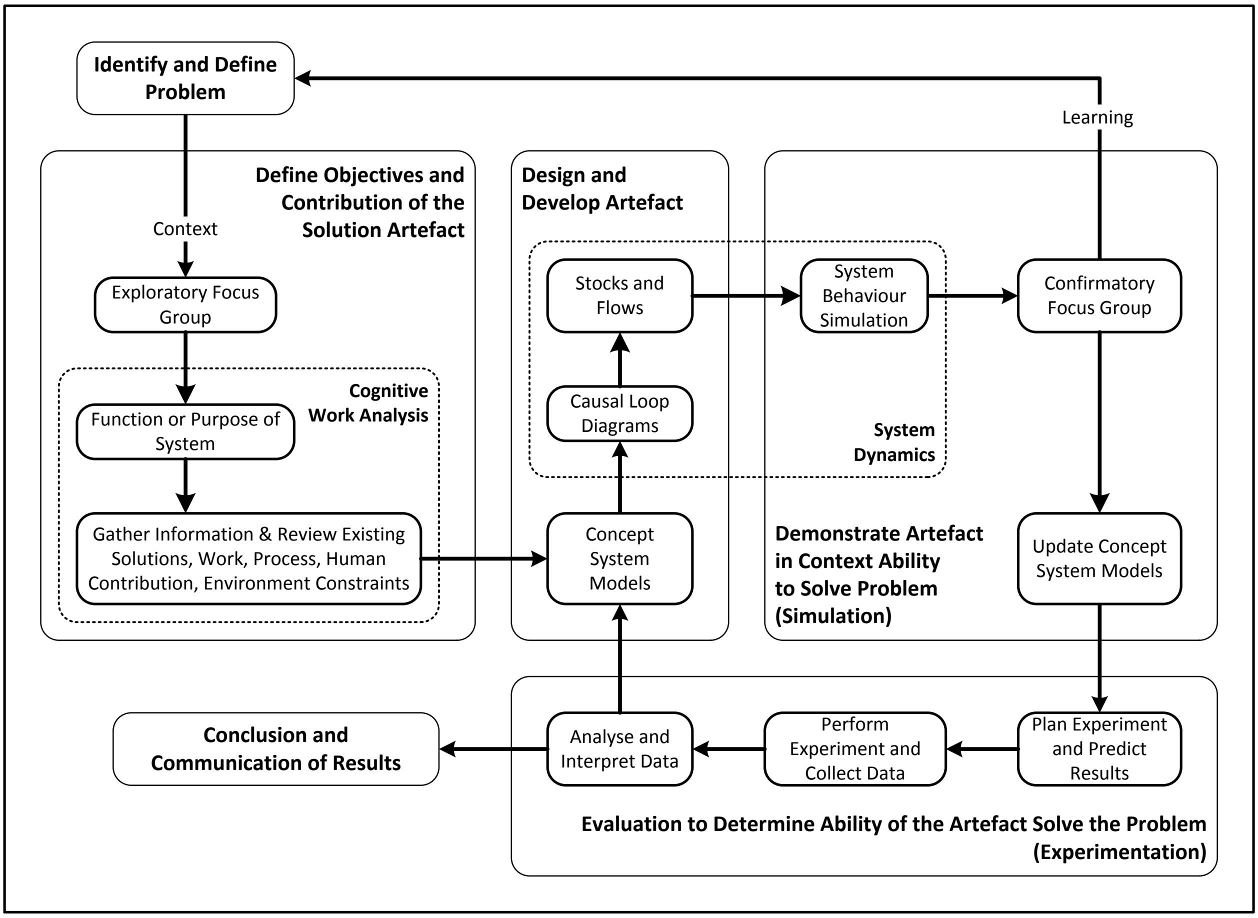

Figure 3. Modelling Methodology

Since SD does not focus on human processes, the inputs of the CWA are crucial in modelling the problem. CWA helps to develop the STS models to initiate SD modelling and simulation. The outputs of this combined modelling approach support planning of experiments and guide the analysis of recorded data. Results of the simulation and utility of the artefact are assessed through a Confirmatory Focus Group (Tremblay et al 2010, Sterman 2000).

The final part of the methodology assesses the artefact focus through experimentation. New knowledge and understanding on the problem and system also lead to improved models. Once an acceptable result is achieved the outcomes can be communicated to the relevant stakeholders. The methodology is demonstrated in the next section on a coordination technology for community security.

Complex Sociotechnical Case Study

This section will demonstrate the ability of the modelling methodology using a case study. The case study will address a coordination, intelligence gathering and intelligence analysis system for community security. The effect of a new collaboration technology on a Community Policing Forum (CPF) and supporting Neighbourhood Watch (NW) systems will be modelled and demonstrated.

CPFs were established in 1995 to ensure police accountability, transparency and effectiveness in the community. A CPF consist of a group of people, from different communities and police representatives, that meet to discuss safety problems in the community (Minnaar 2010). Nowadays the focus of CPF is crime-prevention and community policing. Community policing is a policy and strategy for pro-active utilisation of community resources to achieve more effective and efficient crime control to change crime causing conditions (Meyer & Van Graan 2011).

Public participation and private initiatives, in the form of resident associations and NW, is increasingly taking responsibility for security in communities. The aim is problem-solvingin the neighbourhood and all stakeholders at the local level have to interact, cooperate and exchange information. The police also require information from the community in support of Intelligence Led Policing (ILP). Crime intelligence consists of tactical and strategic intelligence, of which both are essential to successful policing. Tactical intelligence provides information on when and where a crime will take place while strategic intelligence relates to wider incidences such as areas of increased crime. ILP depends on voluntary community involvement and community policing for problem solving and crime prevention.

The main instrument of community policing is patrolling of volunteer neighbourhood members by vehicle. The objective of a NW is to assist in eliminating crime from a neighbourhood to enhance resident safety. Patrols act as the "eyes and ears" of the Police to report incidents, suspicious persons or potential crime scenes without getting involved (Zinn 2010, Meyer & Van Graan 2011). Suitable technology is required to capture information from the community and distribute it to the police. Effectively integrating reports on incidents and suspicious behaviour reported by the NW will be valuable. The case study will focus on enhancing integration between the police, private security company and residents patrolling their neighbourhood in a NW system. This can be viewed as complex STS as it consist of humans interacting with each other in small diverse teams using processes, structure and technology. Since CPF and NW is a complex sociotechnical system, the modelling methodology should be able to determine the effect of new technology on the whole system. Currently the technology utilised is limited as it consists of procedures, radios and a manual paper driven reporting process.

Identify the Problem. Limited crime intelligence hinders effective CPF and NW. Not all criminal related incidents in a residential neighbourhood get reported, including useful information on minor or near incidents. This information may add to intelligence and identification of trends to improve preventative policing. The aim of the proposed technology is to gather and analyse crime intelligence for effectively NW patrol coordination of crime prevention actions. Information and intelligence have to support situation awareness of the control room, patrollers and private security participants. A new technology cannot be dumped into a complex STS, expecting positive results or improvements. The expectation is that the new technology will improve the NW as complex STS, but it is not clear what the resulting behaviour of the system will be. Therefore, the aim of this modelling and analysis effort is to determine how wed based collaboration technology will assist NW and CPF to improve police crime intelligence.

Define Objectives and Contribution of the Solution Artefact. The collaboration technology to be integrated in the NW and CPF system has to record incidents (with text and photos), analyse information (identify patterns, clustering and links), manage distribution of information, coordinate assets (assign and guide responses). The available information from literature is used to populate a WDA, as seen in Figure 4, to determine the relationship between the new technology and the purpose of the system. As seen in literature the purpose of NW is to make the neighbourhood safe for the citizens as well as supporting police intelligence through the CPF. The values and purpose related functions provide the link between the physical elements and the overall system purpose.

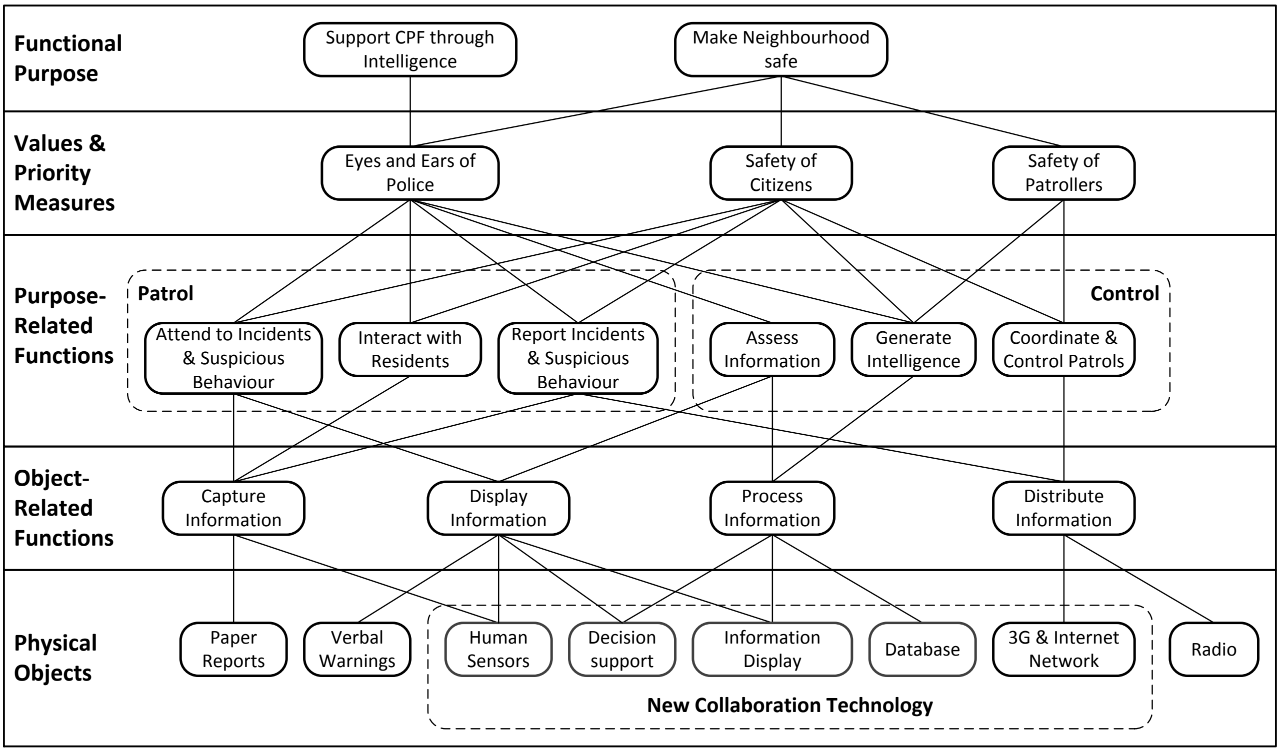

Figure 4. Work Domain Analysis for Neighbourhood Watch

Design and Develop the Artefact. The CWA is used to compile a conceptual functional flow diagram, as seen in Figure 5, for relevant scenarios based on military command and control theory and principles (Alberts & Hayes 2006). The functions from the WDA are sorted in a typical NW process for taking action on detected incidents or warnings from crime intelligence. The aim is to develop models that represent the system structure and behaviour. The structure, as supported by the CWA, indicates that the new technology should make a major contribution. However, the dynamic interaction between the system elements and the environment still needs to be considered.

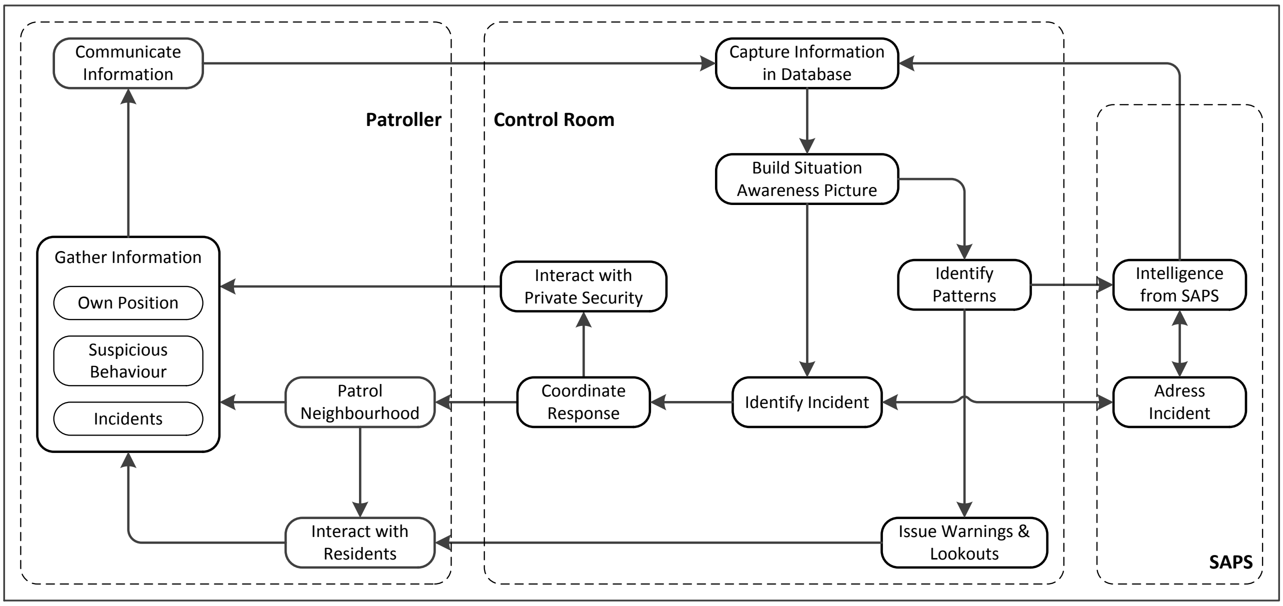

Figure 5. Functional Flow Model

Causal Loop Diagram. The dynamic hypothesis, as supported by the CWA, is that new collaboration technology will make the NW more effective through reporting more suspicious behaviour and attend to incidents faster. As seen in the Causal Loop Diagram in Figure 6, information on incidents and the location of the patrollers will increase the situation awareness of the NW control room. This source of information should boost police intelligence on crime in the environment through proper information exchange interfaces. Feedback from police intelligence will further improve the awareness of the control room to control the patrollers. Increased police intelligence will improve police action to affect a decrease level of criminal activity in the neighbourhood. With the enhanced situation awareness, more criminal activity will be reported as the patrollers will better informed of what to look for. Incidents can be reported directly to the police through dockets for development of crime intelligence or minor incidents and near incidents can be captured through the Neighbourhood Watch patrollers. The intelligence gathering loops through the police and the NW patroller loops will be balancing loops. The generation of situation awareness between the police intelligence, control room and the NW patrollers will be reinforcing loops.

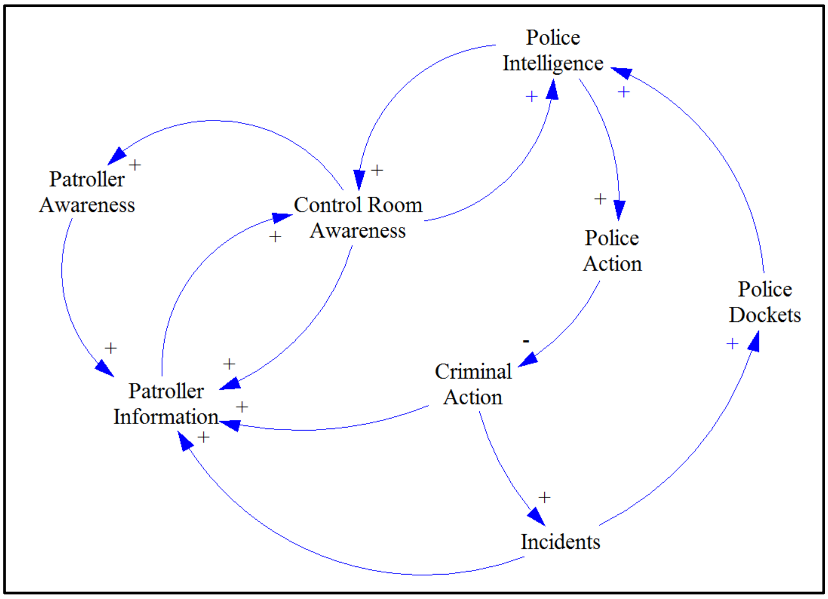

Figure 6. Neighbourhood Watch Causal Loop Diagram

Stock and Flow Diagram. The Causal Loop Diagram (Figure 6), WDA (Figure 4) and Physical System Element diagram (Figure 5) are used to compile a Stock and Flow Diagram as seen in Figure 7. In this context, police information and intelligence are in the same stock because the technology under consideration will not necessarily influence the police information analysis capability. It will only ensure that more information is available. The NW patrols observe and record criminal incidents (including suspicious behaviour or vehicles) to build a database in the CPF (control room). New criminal incidents create new situations which decrease the Intelligence as the new information must still be analysed. This model can now be used to assess the effect of various levels of patrol awareness on the dynamics of the total system.

Demonstrate the Artefact. SD simulations with the Stock and Flow Diagram (Figure 7) are used to analyse the effect of the new technology on the dynamics of the system. Various forms of inputs can be utilised although actual information from the environment is preferred. The outputs will be compared to observations from the actual experimentation with the new technology in the complex STS. The simulations are used to ensure the model makes sense and the factors (leverage points) in the system are understood.

Evaluate the Artefact. Experiments with the new technology in the complex STS will be used to evaluate the hypothesis from the modelling process. Simulation results will be used to plan the measurements in the experiment. Analysis of the experiment result will be used to update the model. The lessons learnt and understanding gained will initiate the process of generating requirements for initiating a formal SE process in implementing the new technology.

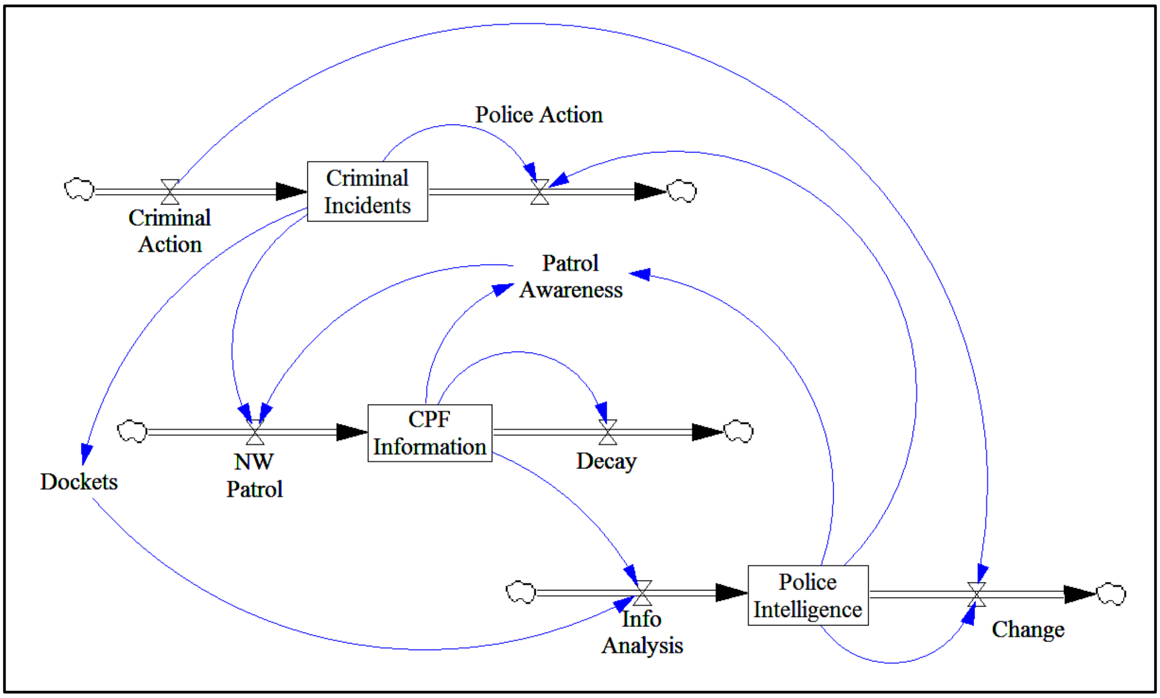

Figure 7. Neighbourhood Watch Stock and Flow Diagram

Conclusion

Careful modelling and analysis are required to support development of a complex STS. This is especially relevant where humans use technology for of decision support and communication, to make sense of a situation in support of coordinating actions. Effective modelling can support experimentation to gain an understanding of the system requirements under diverse conditions.

The modelling methodology needs to capture the human contribution to the system success as well as the dynamic interaction due to effect of the environmental constraints and system operation. Focussing on the specific technology to be implemented alone my miss important aspects required for successful project completion. Also, counter intuitive opportunities presented through creative use of the technology may lead to unexpected gains. The inclusion of CWA and SD in a DSR framework will support modelling these aspects of a complex STS. This paper demonstrated the modelling methodology for NW and CPF in support of police Intelligence.

References

Alberts, D.S. & Hayes, R.E. 2006. *Understanding Command and Control*. CCRP Publication.

Bahill, A.T., Gissing, B. 1998. Re-*evaluating Systems Engineering Concepts Using Systems Thinking*. IEEE Transactions on Systems, Man, and Cybernetics—Part C: Applications and Reviews 28 (4): 516.

Bar-Yam, Y. 2003. *When Systems Engineering Fails - Toward Complex Systems Engineering*. New England Complex Systems Institute, Cambridge, MA, USA.

Baskerville, R., Pries-Heje, J., Venable, J. 2009. *Soft Design Science Methodology*. In proceedings of the 4th International Conference on Design Science Research in Information Systems and Technology, ACM.

Baxter, G., Sommerville, I. 2011. *Socio-Technical Systems: From Design Methods to Systems Engineering*. Interacting with Computers 23 (1): 4.

Bénit-Gbaffou, C. 2006. *Police-Community Partnerships and Responses to Crime: Lessons from Yeoville and Observatory*, Johannesburg. Urban Forum 17 (4).

Bennett, K.B., Posey, S.M., Shattuck, L.G. 2008. *Ecological Interface Design for Military Command and Control*. Journal of Cognitive Engineering and Decision Making 2 (4): 349.

Bostrom, R. P., Heinen, J. S. 1977. *MIS Problems and Failures: A Socio-Technical Perspective*. Part I: The Causes. MIS Quarterly 1 (3): 17.

Buede, D.M., 2000. *Engineering Design of Systems - Models and Methods*. John Wiley & Sons.

Carroll, J. M., Rosson, M. B, 1992. *Getting Around the Task-Artifact Cycle: How to Make Claims and Design by Scenario*. ACM Transactions on Information Systems 10 (2): 181.

Checkland, P., Poulter, J. 2007. *Learning For Action: A Short Definitive Account of Soft Systems Methodology, and its use Practitioners, Teachers and Students*. Wiley, UK.

Checkland, P., Scholes, J. 1990. *Soft Systems Methodology in Action*. Wiley, Chichester, UK.

Cilliers, P. 2002. *Why we cannot know complex things completely*. Emergence 4(1): 77.

Cummings, M. L. 2006. *Can CWA Inform the Design of Networked Intelligent Systems*. In Moving Autonomy Forward Conference.

Forrester, J. W. 1968. *Industrial dynamics—after the first decade*. Management Science 14 (7): 398.

Gell-Mann, M., 1994. *The Quark and the Jaguar*. WH Freeman, New York, USA.

Haskins C. (ed.), 2010. *Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities.* Version 3.2. Revised by M. Krueger, D. Walden, and R. D. Hamelin. San Diego, CA (US): INCOSE.

Hevner, A. 2007. *A Three Cycle View of Design Science Research*. Scandinavian Journal of Information Systems 19 (2): 87.

Hevner, A., March, S., Park, J., Ram, S. 2004. *Design Science in Information Systems Research*. MIS Quarterly 28 (1): 75.

Hitchins, D. K. 2008. *Systems Engineering: a 21st Century Systems Methodology*. Wiley. com.

Hybertson, D.W. 2009. *Model-Orientated Systems Engineering Science: A Unifying Framework for Traditional and Complex Systems*. CRC Press.

Janlert, L. E., Stolterman, E. 2010. *Complex interaction*. ACM Transcript. Compututer-Human Interaction 17 (2).

Jenkins, D.P., Stanton, N.A., Walker, G.H., Salmon, P.M. 2009. *Cognitive Work Analysis: Coping with Complexity*. Ashgate Publishing, UK.

Lintern, G. 2008. *The Theoretical Foundation of Cognitive Work Analysis*. In Bisantz, Amy & Burns, Catherine (eds), Applications of Cognitive Work Analysis, CRC Press.

Lintern, G. 2012. Work-focused analysis and design. Cognitive Technical Work 14: 71. Springer-Verlag London Limited

Maier, M. W., Rechtin, E. 2000. *The art of systems architecting* (Vol. 2). Boca Raton: CRC press.

March, S., Smith, G. 1995. *Design and Natural Science Research on Information Technology*. Decision Support Systems 15: 251.

Maria, A. 1997. *Introduction to modeling and simulation*. In Proceedings of the 29th conference on Winter simulation. IEEE Computer Society.

Meadows, D. 2008. *Thinking in Systems: A Primer*. Chelsea Green Publishing.

Meyer, M., Van Graan, J.G. 2011. *Effective Community Policing in Practice: The Roodekrans Neighbourhood Watch Case Study, West Rand*. Southern African Journal of Criminology. Acta Criminologica 24 (2).

Minnaar, A. 2010. *The Changing Face of 'Community Policing' in South Africa, Post- 1994*. Acta Criminologica: Southern African Journal of Criminology. CRIMSA 2009 Conference Special Edition No 2.

Naikar, N, Moylan, A, Pearce, B. 2006. *Analysing Activity in Complex Systems with Cognitive Work Analysis: Concepts, Guidelines and Case Study for Control Task Analysis*. Theoretical Issues in Ergonomic Science 7 (8): 371.

Oliver, D.W., Andary, J.F., Frisch, H. 2009. *Model-Based Systems Engineering*. In Handbook of Systems Engineering and Management, Second Edition, Eds Sage A.P. & Rouse W.B., John Wiley & Sons, pp. 1361.

Papachristos, G. 2011. *A System Dynamics Model of Socio-Technical Regime Transitions*. Environmental Innovation and Societal Transitions 1 (2): 202.

Peffers, K., Tuunanen, T., Rothenberger, M., and Chatterjee, S. 2007. *A Design Science Research Methodology for Information Systems Research*. Journal of Management Information Systems 24 (3): 45.

Polack, F. A., Hoverd, T., Sampson, A. T., Stepney, S., Timmis, J. 2008. *Complex systems models: Engineering simulations*. In Artificial Life XI: Proceedings of the Eleventh International Conference on the Simulation and Synthesis of Living Systems (pp. 482). MIT Press.

Ramos, A. L., Ferreira, J. V., Barceló, J. 2010. *Revisiting the similar process to engineer the contemporary systems*. Journal of Systems Science and Systems Engineering, 19 (3): 321.

Reiman, T., Oedewald, P. 2007. *Assessment of complex sociotechnical systems – Theoretical Issues Concerning the Use of Organizational Culture and Organizational Core Task Concepts*. Safety Science 45:745.

Rittel, H.W.J., Webber, M.M. 1973. *Dilemmas in a General Theory of Planning*. Policy Sciences 4 (2): 155.

Rudestam, K.E. and Newton, R.R. 1992. *Surviving your Dissertation: A Comprehensive Guide to Content and Process*. SAGE, London.

Sheard, S.A., Mostashari, A. 2009. *Principles of Complex Systems for Systems Engineering*. Systems Engineering 12 (4): 295.

Simon, H. A. 1996. *The Sciences of the Artificial*. (3rd ed.), MIT Press, Cambridge, MA.

Smith, R. 2007. *The Utility of Force: The Art of War in the Modern World*. Alfred A. Knopf, Borzoi Books.

Stanton, N. A., Baber, C., Harris, D. 2012. *Modelling Command and Control: Event Analysis of Systemic Teamwork*. Ashgate Publishing, Ltd.

Sterman, J. D. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. New York: Irwin/McGraw-Hill.

Sterman, J.D. 1994. *Learning in and About Complex Systems*. System Dynamics Review 10 (2): 291.

Tremblay, M. C., Hevner, A. R., Berndt, D. J. 2010. *Focus Groups for Artifact Refinement and Evaluation in Design Research*. Communications of the Association for Information Systems 26 (1): 27.

Trist, E.L. 1981. *The Evolution of Socio-Technical Systems: A Conceptual Framework and an Action Research Program*. Ontario Quality of Working Life Center, Occasional Paper no. 2.

Venable, J. 2006. *A Framework for Design Science Research Activities*. Emerging Trends and Challenges in Information Technology Management, Volume 1 and Volume 2, Ed Khosrow-

Pour, M., Idea Group Inc.

Vicente, K., 1999. Cogni*tive Work Analysis: Towards Safe, Productive and Healthy Computer-Based Work*. Lawrence Erlbaum Associates.

Walker, G.H., Stanton, N.A., Salmon, P.M., Jenkins D.P. 2008. *A Review of Sociotechnical Systems Theory: A Classic Concept for New Command and Control Paradigms*. Theoretical Issues in Ergonomics Science 9 (6): 479.

Walker, G.H., Stanton, N.A., Salmon, P.M., Jenkins D.P. 2009. *From Clansman to Bowman: HFI Principles for NEC System Design*. The International C2 Journal 3 (2): 1.

White, B.E. 2010. *Complex Adaptive Systems Engineering*. Aerospace and Electronic Systems Magazine, IEEE, 25 (12): 16.

Wolstenholme, E. F., 1990. *System Enquiry: a System Dynamics Approach*. John Wiley & Sons.

Zinn, R. 2010. *Sourcing Crime Intelligence from Incarcerated House Robbers*. SA Crime Quarterly no 32.

Biography

Rudolph Oosthuizen. On qualification as Electronic Engineer in 1995 he worked in the South African Air Force on Command and Control and Electronic Warfare systems. He was the Chief Engineer of the Electronic Warfare Centre from 2000 to 2006. Beginning 2007 he was posted to Directorate Command and Control Systems at Air Force HQ as the Chief System Engineer. In 2008 he joined CSIR as a Systems Engineer. Currently, he is busy with PhD studies into Complex Systems Engineering and application thereof into Command and Control. The focus is on Sense-Making and Decision-Making support as part of the Command and Control process.

Leon Pretorius. Leon Pretorius obtained the D Eng degree (1983) from the University of Pretoria, South Africa. He has more than 37 years professional, engineering, academic, and academic management experience. He was professor at the University of Johannesburg, South Africa until 2007. In 2004 he was the last Dean of Engineering at the Rand Afrikaans University prior to the merger of RAU and TWR when he became Executive Dean of Engineering and the Built Environment at the University of Johannesburg in 2005. He is currently Professor in the Graduate School of Technology Management at University of Pretoria. He has concurrently been active as specialist consultant and researcher in engineering industry since 1980, He has supervised more than 170 master including 40 PhD students in engineering as well as engineering and technology management. He has also published more than 174 technical conference papers and peer reviewed journal articles as author and co-author in his fields of expertise. He is an Honorary Fellow of SAIMechE, member of SAIIE, Member of ASME and Member of IEEE.