Proceedings of the 3rd Annual System Dynamics Conference

16th November 2015
Eskom Research Testing & Development Centre; Johannesburg; South Africa

Collaborative Partners:
Eskom & the South Africa System Dynamics Chapter
Proceedings of the

3rd Annual System Dynamics

Conference
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16th November 2015

Eskom Research Testing & Development, South Africa


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Edited by: Nalini Sookanan Pillay

Publisher: Eskom SOC, Lower Germiston Road, Rosherville South Africa

To obtain additional copies of these proceedings or to learn more about the Annual System Dynamics Conference, contact:

Nalini Sookanan Pillay Pr.Eng
Email: Nalini.pillay@eskom.co.za

Or Mapule (Minah) Ntsoane
Email: NtsoanMM@eskom.co.za

Or Access the Website for the South African System Dynamics Chapter: http://www.systemdynamics.org.za
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Welcome

Eskom SOC collaboratively hosted the 3rd System Dynamics Conference in South Africa on the 16th November 2015. Once again, the Conference served as a vehicle to discuss and share existing system dynamics projects and research by various institutes and organizations, while creating opportunities for networking and new research ideas. The Conference was opened by Mr Barry MacColl, General Manager – Eskom Research Testing & Development and the keynote speaker was Professor David Rubin from the University of Witwatersrand who spoke about the application of system dynamics in Health Sciences.

Topics covered were diverse and it was clear that the system dynamics approaches assisted in developing an understanding of the behaviour of these systems over time, through multiple scenarios that provided foresight intelligence and insights on how to manage change. Several of the systems which were simulated were complex with variables that interacted with each other non-linearly in a “network-like” causal structure, however, a few topics went beyond modelling organizational complexities to applications in everyday, realistic activities.

The South African System Dynamics Chapter incentivised this years Conference by donating trophies to the following participants who received accolades through a process of voting:

- **Best Student Paper**: Willem Jonker & Theodore A York: *A System Dynamics Approach to Understand the Implications of a Green Economy Transition in the Western Cape Province of South Africa*
- **Best Presentation**: Andries Botha, Toyota SA: *Ponzi Schemes - A System Dynamics Perspective*.

The 4th Annual South African System Dynamics Conference will be held in Stellenbosch, South Africa, hope to see you all there!

**Nalini Sooknanan Pillay**

Head: System Dynamics CoE, Eskom Research Testing & Development  
Vice-President: South African System Dynamics Chapter
Partners and Conference Organizers

**Eskom Research Testing & Development – System Dynamics Centre:**
Mapule Ntsoane, Daniel Booyens, Naledi Memela, Talitha Koegelenberg, Corné Du Plooy, Nombuso Sibeko, Chris Gross, Nalini Sooknanan Pillay

**South African Chapter of the System Dynamics Society:**
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Conference Chair and Submission Review Volunteers

**Conference Session Chairs:**
Chris Gross – Eskom SOC
Andries Botha - Toyota South Africa
Dr Josephine Musango – University of Stellenbosch
Prof Alan Brent – University of Stellenbosch
Nic Cloete Hopkins – University of Witwatersrand

Keynote Speaker

**Professor David Rubin – University of Witwatersrand**
Conference Participants

The following institutes and organizations were represented:

- Eskom Divisions & Groups
- SASOL Inzalo Foundation
- CSIR
- Sustainable Concepts (Pty) Ltd
- Dynamic Strategies
- Nedbank
- EON
- Department of Energy
- University of Stellenbosch
- University of Witwatersrand (Including the Transnet Centre of Systems Engineering)
- University of Cape Town (including the Energy Research Centre)
- University of Pretoria
- Tshwane University of Technology
- Da Vinci Institute
- IDC
- Global Prospectus Training
- Gordon Institute of Business Science
- Toyota South Africa
- KnowlEdge Srl.
EXTENDED ABSTRACTS
KEYNOTE

System Dynamics in the Making of a Professional: A Health Sciences Perspective

David M. Rubin

Biomedical Engineering Research Group; School of Electrical & Information Engineering; University of Witwatersrand, South Africa; Email: d.rubin@ee.wits.ac.za

ABSTRACT

System Dynamics has broad applicability across numerous disciplines, and knowledge of and fluency with System Dynamics thus has the potential to benefit the practice of a wide range of professions. A number of professional activities are well known to include a heavy dose of systems thinking; examples of this include environmental management, urban planning and economics. The need for systems thinking in various professional activities is not always recognised, however there is little doubt that many fields could benefit from an enhanced education in systems approaches. This talk focuses primarily on the teaching of System Dynamics as part of the training of medical professionals as a means of achieving a more rigorous thought process and a deeper appreciation for the role of complexity in their discipline. An outline of the courses taught to Medical, Pharmacy, and Health Science students at the University of the Witwatersrand, Johannesburg is given. This includes a discussion on the nature of medical problems and their suitability for systems analysis.

Particular emphasis is placed on the hierarchical nature of the “medical system”, starting with the molecular aspects and extending this to the sub-cellular, cellular, organ, and human body levels, followed by further extension of its utility in the local and general healthcare systems. Examples are given of the various systems studied at each level, such as pharmacokinetics, enzyme kinetics, cardiovascular dynamics, heat transfer in the human body, endocrinology, hospital logistics and health economics. This is followed by some discussion on the anticipated effects that this training has on the students’ approach to problem solving in the context of clinical medicine. Of critical importance is the attitudes expressed by students in their endeavour to master the approach to System Dynamics and their perceptions of its utility for the future careers. This is likely to vary among various professional disciplines, and insights gained so far from trainee medical professionals is discussed. The benefits of training in System Dynamics for medical professionals may be extended to the training of other professions where, like clinical medicine, a systems approach has not traditionally been used in the undergraduate training process.
A System Dynamics Approach to Understand the Implications of a Green Economy Transition in the Western Cape Province of South Africa

Josephine K Musango*1, Alan C Brent2, Jacobus B Smit van Niekerk2, Willem D Jonker2, Aliza P Pienaar2, Theodore A York2, Juan Oosthuizen2, Lize Duminy2, Imke H de Kock 2

*1 Corresponding Author, Josephine.Musango@spl.sun.ac.za
1 School of Public Leadership, and the Centre for Renewable and Sustainable Energy Studies (CRSES), Stellenbosch University, Private Bag X1 Matieland, 7602; South Africa
2 Department of Industrial Engineering, and the Centre for Renewable and Sustainable Energy Studies (CRSES), Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa; Tel: +27 21 808 4069; Email: acb@sun.ac.za

ABSTRACT

The United Nations Environment Programme (2010) defines a green economy as “an economy that will result in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities”. To this end, various bodies, policies and structures have been aligned to address the effect of human progression (socially and economically) on the earths’ limited natural resources.

Facilitating the transition to a green economy presents opportunities for national, provincial and local governments. A number of initiatives (on all levels of government) relating to the green economy within South Africa emerged at the 2010 Green Economy Summit, and the identified drivers to a green economy include, amongst others: the need to move towards low carbon economies; decreasing scarcity of material resources; and the need for improved and sustained service delivery (South African Government, 2010). Previous studies developed frameworks and models to identify and investigate the aspects of green economy transitioning within South Africa (Musango et al., 2014) which could aid in managing the various green economy drivers without noteworthy negative impacts on other sectors. However, Musango et al. (2015) noted that the analysis of green economy transitions generally happens on a national level, while many of the green economy interventions take place on a provincial or local government level. It is thus recommended that a green economy analysis be conducted on provincial level, in order to indicate to decision-makers and stakeholders what the effects and scale of investment and intervention required are.
As part of the national initiative to address climate change, the Western Cape Government (2013) created the Western Cape Green Economy Strategy Framework, which identifies five drivers for transitioning to green economy. These drivers include: smart living and working, smart mobility, smart ecosystems, smart agri-production, and smart enterprise. The study with which this paper is concerned is guided by the said strategy and focuses specifically on water, agriculture, transport infrastructure, renewable energies, energy production, CO₂ emissions, and public services.

The vast majority of challenges relating to climate change and the depletion of limited natural resources are due to the unintended and unforeseen consequences of past actions. For analysis and assessment of such systems, an approach should thus be used that can indicate the complex dynamic effects and relations of policies, strategies and decisions. System dynamics was identified as a modelling approach that enables the understanding of complex real world problems over time in order to guide decision-making to ultimately achieve sustainable long-term solutions (Musango et al., 2015). The usefulness of system dynamics in describing complex socio-ecologic systems has been established in previous studies (Musango et al., 2014), and was subsequently used to build a model that encapsulates the transition to a green economy in the Western Cape Province. Key variables and indicators were identified within the sectors that contribute towards a green economy. The model aims to indicate the behaviour, or outcomes, of these indicators until 2040, aiming to identify, and recommend on, strategic intervention points.

The developed model consists of sub-models that constitute a larger holistic model with numerous interaction and feedback effects. There are 14 sub-models, of which some have been further developed to subsequently deliver simulation results under different scenarios for each sub-model. Three sub-models are in an advanced stage of development, these are the agriculture, biofuel, and transport infrastructure models; and their preliminary results have yielded important findings.

The agriculture model was developed to better understand the impact sustainable farming (organic and conservation) practices would have on the food production sector of the Western Cape Province. The model consists of the ten major food crop commodities (grains, vegetables and fruit) produced in the Western Cape Province, and how their annual production is affected by conventional, organic and conservation farming practices. Organic yield is assumed to be significantly less than that of conventional food crop and can be applied to grains, vegetables and fruit. Conservation yield is assumed to be more than conventional yield, but can only be applied to grains. The agriculture model has three green economy scenarios and one business-as-usual scenario, which is used as the baseline. The three green scenarios test different organic yield cases, namely: where organic yield is 65%, 75% and 100% of that of conventional yield.
Sustainable farming practices are also used more intensively in these three scenarios. The model results highlighted the fact that if organic yields cannot match conventional yields, then sustainable farming will not reduce CO₂ emissions sufficiently to justify the significant financial investment required.

The biofuel model was developed as part of a project and policy evaluation to determine the feasibility and impacts of the Western Cape Province forming part of the National Mandatory Biofuel blending policy. The effects of establishing a bioethanol plant, producing 160 million litres per year using triticale as feedstock was modelled and it was found that a strong business case for such a project exists. A biodiesel facility producing 35 million litres/year, using canola as feedstock was deemed financially infeasible. The project evaluation further looked at the alternative scenario where biofuel is produced elsewhere in the country and transported to the Western Cape Province for blending. All of the scenarios were evaluated based on the financial implications and effects on emissions and employment, to ultimately recommend the way forward for the biofuel sector in the Western Cape Province. It was concluded that a large scale bioethanol facility using biomass as energy source could prove beneficial to the Western Cape Province as part of the transition to a green economy.

The transport infrastructure model was developed to analyse the strategic goals identified in a green economy transition. These included the reduction of carbon emissions from municipal transport networks, and the need for a vast investment into the development of a more energy efficient and sustainable infrastructure network. The transport infrastructure model investigated the implications and impacts of improving public transport, making private transport more efficient, and creating a modal shift in freight transportation to rail as the crux. The key findings of the research indicate that through the investment into a better public transport system, as well as shifting the movement of freight onto the rail network, would have positive long-term environmental, social and economic effects. These include reduced truck and private vehicle numbers on the roads resulting in better road conditions, lower traffic densities, lower CO₂ emissions, and reduced diesel and petrol demand within the Western Cape Province. For example, the combination of the two major intervention strategies of public transport and rail freight yielded a significant reduction in emissions from the transport sector, up to 17.89%, compared to the business-as-usual scenario. However, a significant investment is required to facilitate the transition of transport infrastructure, which is manageable and achievable through strategic development.

This study aimed to build a knowledge base of, and insight into, the different systems and complexities within the context of a green economy transition in the Western Cape Province.
across all sectors. This involved investigating the interplays between society, economics and the environment in identifying how each sector operates and the importance it holds on all levels. The system dynamics model for all major contributing sectors in the economy was developed, and the various strategies and policy changes were simulated in comparison to a business as usual scenario. This enabled the critical analysis of the impacts and implications of such strategies into the future.

**Keywords:** agriculture, biofuel, transportation, infrastructure, green economy, system dynamics, Western Cape Province.

**REFERENCES**


Project Prioritisation Using System Dynamics

Nombuso L Sibeko*¹, Nalini S Pillay², Simon Higgins³

¹,²Research, Testing and Development, Eskom, South Africa.
E-mails: ¹ sibekonl@eskom.co.za; ² pillayna@eskom.co.za
³ Generation, Eskom, South Africa, E-mail: higginsa@eskom.co.za

INTRODUCTION
A system dynamics methodology was followed to develop a decision support tool to assist in strategic planning and multi-criteria project prioritisation while allowing dynamic scenario changes to assess the impact of various project prioritisation decisions within a financially constrained organisation. Most conventional project prioritisation methods evaluate and prioritise projects in isolation with no interdependency consideration. The simulator compares the effects of prioritising projects in isolation versus prioritising projects based on their interdependencies with respect to funds allocation, time-to-benefit attainment and cost benefit trade-offs.

METHODOLOGY
Part of the system dynamics methodology involved developing a causal loop diagram (Figure 1), to assist with identifying the potential key driving forces and their cause and effect relationships. The initial prioritisation of a suite of projects is typically based on the impact the projects are expected to have on improving the business unit’s key performance indicators (KPIs) which should align with the company objectives. The projects that have the highest expected benefit will be ranked higher; this determines the initial relative importance of the project. Figure 1 analyses the forces that interact to reinforce or reduce the relative importance of the project. Loop R1 captures the effect of resource allocation, which is dependent on the relative importance of the project, and the impact that resource allocation will have in closing the gap between the project’s expected benefits and the actual benefits.
Loop R2 looks at senior management’s need to deliver and their preference to fund and resource projects that will deliver in a short time frame. Loop R1 and R2 are bound by the project management abilities. Loop R3 traces the effect of return on investment as the gap between the expected benefit of the project and its actual benefit decreases.

A literature review was undertaken to understand global best practices for project prioritisation; this served as the base case in the simulator, for project prioritisation with no dependency considerations. The simple multi-attribute rating technique (SMART) was selected, this technique was chosen due to its simplified algorithm; and it not being time intensive, which is important for those involved in the decision making process (Zardari et al., 2015). SMART is utility-based and has the ability to handle both quantitative and qualitative data. One of the limitations of this technique is that it ignores the interrelationships between parameters and the ratings of the alternatives are not relative, thus changing the number of projects evaluated will not in itself change the decision scores of the original projects.

SMART requires the decision makers to identify the criteria that they deem important for project prioritisation as well as the evaluation methods for the criteria. The decision makers must then assign a weight to each criterion, and the weights must sum to 100. Seven criteria were identified,
namely: strategic alignment to company objectives, project criticality, potential return on investment, execution risk, project time frame, project enablers, and public perception.

Figure 2 shows the system architecture map (SAM) of the simulator, which provides an overview of the simulator structures and the overall system bounded variables. The simulator has a time frame of 60 months, and was developed using iSee Stella software with a project suite limited to five.

The stakeholders in the assessment of projects include:

- An oversight committee: calibrates and initialises the simulator by assigning unique ranks to the criteria and sub-criteria, the ranks are converted to weights, using rank order centroid method (Roszkowska, 2013).
- Project team leaders: provide the project details relating to the criteria.

The criterion ranks and project data relating to the criterion are the exogenous inputs. The projects are evaluated against each criterion and a criterion score calculated. The simulator calculates a weighted average score for each project. The scores may be influenced by externalities such as regulatory or legislative priorities. An interdependency prioritisation schedule is also determined and the simulator then compares funds allocation, time-to-benefits attainment and cost benefits trade-offs of the two prioritisation methods.

Figure 2: System Architecture Map

RESULTS

The simulator is still under development but the first phase of the simulator, looking at project prioritisation with no interdependency, has been completed. A suite of 5 projects with the Water Research Portfolio was chosen as the pilot test case. The simulator was initialised by a contingent of research strategy managers. Four of the five projects had a legislative requirement with the same deadline of 28 February 2022. The project scores were between 62.25 and 52.49. The
project data for project evaluation was very similar as the projects are from the same environment and work together in fulfilling their intended purposes. However, there was still enough variability between projects for the simulator to determine a prioritisation schedule. The project prioritisation schedule after legislative requirements were considered normalised the ratings of 4 projects to within the same range (62.10-62.25).

CONCLUSIONS
These results will be compared to those obtained in the second phase of simulator development; however, initial engagements with subject matter experts validated the results from experience. The second phase of the simulator is the development of the prioritisation schedule of the projects based on their interdependencies and to compare funds allocation, time to benefits attainment and cost-vs-benefits for the two prioritisation methods.

Keywords: Eskom, Inter-dependency, Prioritisation, Project, System Dynamics

ACKNOWLEDGMENTS
Danie Booyens and Corne du Plooy

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ABSTRACT

Demineralized (demin) water is when the ions and minerals are removed from the water so that the water can be used for a specialized process. In Eskom, this water is used in the water/steam cycle to produce electricity. During this cycle, the liquid water in the system is heated to high pressure and temperature steam to drive the turbines and generator. During this evaporation process, any minerals will precipitate and potentially form scaling inside of the boiler tubes. This could easily lead to boiler tube leaks due to insufficient cooling caused by scaling. The other possible consequence is corrosion on the boiler tubes which could lead to boiler tube leaks (PDH). To prevent these damages in plant that cannot be sustainably maintained, they have to negate these consequences by using demin water.

Two of the most prominent technology types used for demin water production is membrane filtration in the form of reverse osmosis and deionization in the form of ion exchange resin (ENViCARE). The first technology works on the principle of forcing dirty water through an extremely fine chemically active filter through the use of high pressures. These high pressures are very energy intensive and easily damage the membranes which then needs to replaced and are very expensive.

Ion exchange works on the principle of trading one ion type in solution with an ion located inside the resin. One of the drivers of this process is the selectivity of the ion in the raw water to the ion in the resin (DOWEX, 2000). This selectivity causes the ion in the solution to exchange places with the ion in the resin. This takes place until the resin does not have significant exchange points left, or the raw water does not have a high enough concentration of ions (which will influence the selectivity). What gives this process the edge in its class, is that it is completely reversible. So the ions which are absorbed by the ion exchange process can be removed through the process called regeneration. During regeneration a very strong acid or base (depending on the type of resin) will exchange places with the ions in the resin resulting in the ability to reuse the resin to treat the raw water again.
There are two different classifications of ions. They are either positive referred to as cations or negative, anions. The cations can be ions such as Sodium, Magnesium, Calcium (Na\(^{+}\), Mg\(^{2+}\), Ca\(^{2+}\)) etc. The anions can be ions like Sulphate, Chlorine, Carbonic acid (SO\(_{4}\)\(^{2-}\), Cl\(^{-}\), HCO\(_{3}\)\(^{-}\)) etc. These two types of ions are absorbed by two types of resin. The resin are generally referred to cation or anion resin. Cation resins have the ability to remove cations out of the raw water while the anion resin can remove the anions inside of the raw water.

Eskom’s use of these resins varies with respect to process configurations depending on the power station. The differences in configuration of the demin trains were investigated and then a system dynamics model, using iSee Stella, was built for the different configurations. Station visits revealed that depending on the water quality and age of the technology, the process configuration was different. It was different to such an extent that separate, structural simulations had to be constructed for each of the power stations. One set of vessels (cation, anion, mixed bed) is defined as a train. Each train is designed to cope with the demin water consumption of the whole station. The other two are for regeneration and one is kept on standby. In Eskom, three of each of these sets of vessels is found on the station. This focus of the paper is to highlight the learning lessons while simulating the different configurations.

The first difference in process is due to the initial design of vessel layout. The basic building blocks are cation vessels, anion (weak base and strong base) vessels, mixed beds, and the degasser. Depending on the water quality, these vessels will be selected as well as their sizes and flows specified for operation. Besides the vessel types, there are also the inherent system choices that were made when it was designed. There were three different types observed from three different stations at Eskom, namely: Duvha, Kriel and Grootvlei. The first being series train operation, the second is cross-feeding from the one train to the other and the last (oldest) is the use of common sumps between the vessels. The workings for 2 of these systems are discussed further in this extended abstract.

All three of these systems look very different and require different structures but their outputs are very similar. The first series train operation, the three trains are connected in such a way to keep each train separate. This configuration can be seen in

Figure 1. The difficulty of integrating the three trains mathematically was investigated using iSee Stella and some feedback loops were allocated to the system. One difficulty was deciding when to put which trains online and offline. Since not all the trains should be online at the same time to prevent synchronized exhaustion of the beds, there was System Dynamics Structure built to incorporate the priority of the trains and current status of the trains. The user then specifies how many trains should optimally be online at the same time and the simulation will then strive to reach this number of trains by putting trains on standby or taking them off of standby. Another tricky part of train integration was
the system limit of only being able to do one type of regeneration at a time. This was handled by creating one regeneration structure for each type of vessel. It was constructed in such a way that it will work like a bottle neck and only allows one regeneration action through at a time.

The Common Sump Configuration was where each of the trains’ cation outflows enters into the same degasser sump. From this common sump, water is drawn to the anion vessels (A1, A2, A3 in diagram) and then again flows into the common Anion Sump. In this case the mathematics required the vessels to be regarded as separate production units and the train switching explained above was required for each type of vessel.

![Diagram of Series Train and Common Sump Configuration](image)

Figure 1: Series Train and Common Sump Configuration

The sumps introduce two new state variables which require to be monitored so that demin water can be produced. The regeneration structure uses feedback loops for the regeneration process. Another long term system operation effect is when the Brine Washes are skipped. This will lead to the reduction in throughput of the anions and ultimately reduce the amount of demin water that the plant can produce in one cycle.

The final process was using the data that was available from the station to re-create the history of the stations results and compare that to what the simulations gave. This data evaluation, interpretation and analysis are referred to as data mining and are discussed in this project. The different configurations required a different approach to solve the problem of simulating the system. The system is complex in the sense of integration and regeneration of trains.
In conclusion, using a system dynamics approach was very different than the conventional method of linear optimization. In linear optimization regeneration would easily be done by just switching on and off by using a discreet variable, but by using System Dynamics, a stock and flow had to be used to simulate the process. This resulted in multiple stock-flow diagrams to simulate the different vessels and regeneration. It was interesting to use stocks to keep track of statuses of the vessels. The feedback effect of skipping regenerations was built into the structure and this was relatively easy to do in a system dynamics model and the effect could be seen on the anion throughputs. Another aspect that made the use of stocks and flows easier was that the tanks as well as vessel throughputs, these could easily be represented as stocks. It is therefore possible to use a system dynamics tool to simulate an operational complex system.

**Keywords:** Eskom, System Dynamics, Demin Water Production, Ion Exchange, Simulation

**ACKNOWLEDGMENTS**
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Using SD Modelling to Explore the Complex Social, Biophysical and Political Interactions Involved in Establishing Water Security within the Selati Catchment in the Limpopo Province of South Africa.

W. Jonker*1, T. York1, J.K. Clifford-Holmes2, H. Retief2 and S. Pollard2

1 Department of Industrial Engineering, Stellenbosch University, SOUTH AFRICA
E-mails: *15608700@sun.ac.za; 16062221@sun.ac.za

2 Association for Water and Rural Development (AWARD), No. 14 Safari Junction, Hoedspruit, Limpopo, 1380, South Africa.
E-mails: jai.clifford.holmes@gmail.com, hugo@award.org.za, sharon@award.org.za

ABSTRACT
RESILIM-O is a project implemented by the Association for Water and Rural Development (AWARD), which aims to enhance resilience of people and ecosystems in the Limpopo River Basin through improved water resource management and conservation of biodiversity and ecosystems. The Selati water catchment area in the Limpopo Province is a unique area due to the multitude of social, environmental and political factors affecting water security and direct dependence on water in the area. The Selati River is a major tributary to the Olifants River which flows through the Kruger National Park and into the Massinger dam in Mozambique. The key concerns in the Selati catchment are centered on establishing water security (in terms of flow and quality) for functioning ecosystem services in support of human activities. The recreational and non-consumptive benefits of potable flowing water in the region are also of great relevance and importance.

The Selati catchment can be divided into three regions (upper, middle and lower) categorised by distinct activities within each of the regions. The upper Selati is dominated by commercial agricultural activities which places the river system under immense pressure, as the majority of these agricultural activities are under irrigation. The upper Selati further contains within it a variety of socio-ecological complexities, through communities impacting and being directly dependent on ecosystem services provided by the river system. A Land reform and restitution programme is one of the big drivers for change in social, land use and water use dynamics in the upper region. The middle Selati is mainly comprised of game farms, who use ground water to sustain ecosystems and very little social interaction is present within this region. The impacting factors in the lower Selati region are diverse and some of the country’s largest mining operations...
are situated on the banks of the Selati River. Although mines are required to comply with water licensing requirements, the dynamics influencing the enforcement and monitoring of mining discharge are complex and inefficient. Mining tailing dams (currently unlined) pose a serious threat to ecosystem services downstream. The water quality is further influenced by three Waste Water Treatment Works (WWTW) discharging into the river. Water quality regulations are in place to monitor and regulate the quality of discharge by individual WWTW, however, the cumulative effects of the three WWTW situated in close proximity combined with seepage and possible spills from the mining sector, could have major downstream impacts on human health and well-being, functioning ecosystems and ecotourism. Communities, private game farms, farmers and the Kruger National Park are some of the parties directly influenced by poor water quality.

Land reform is causing the land use to change and results in changing water use and availability patterns. An irrigation scheme (which sees the majority of the Selati River diverted into an irrigation canal) in the upper Selati has severe impacts water use in the area. The Selati River, which was once perennial, no longer achieves the flow required to sustain ecosystems and communities that are dependent on the river. The impacts of the mining and WWTW on flow and quality of the river has also raised some concern in the lower Selati. Various communities within the Selati catchment rely on the ecosystem services and recreational uses provided and sustained by the river. Unforeseen or unexpected changes in water quality and flow could be detrimental to local communities. The impact on ecotourism within the game reserves downstream could also have major implications from an economic perspective.

Existing land use and hydrology models can indicate the expected biophysical impacts of mining activities, climate change and policy change scenarios with great accuracy. However, there is a need, for a platform that can incorporate both quantitative and qualitative elements of the real world problems in the Selati catchment with existing models. System Dynamic Modeling (SDM) is proposed as an approach that can simulate the real world behavior of systems, where inputs can be drawn from existing models. A system dynamic model (ResiMod) serves as a central platform to combine the accuracy of the available biophysical models with the socio-ecological aspects of the catchment.

Figure 2 schematically shows the iterative interaction between ResiMod and the existing models, where ResiMod will draw both quantitative and qualitative data from the models. These models include a Water Quality Systems Assessment Model (WQSAM) and Global Climate Models (GCMs) which are downscaled to the Limpopo basin.
ResiMod will be built through some initial “traditional” behind the scenes modelling and then progress to incorporate elements of group model building, participatory stakeholder engagement and Agile SD modelling to ensure that the socio-ecological system is accurately rendered. ResiMod comprises of multiple sub-models rather than one large model and incorporates land uses into the following sub-models:

- Water resources (surface and ground water and inter-flow);
- Human population (domestic water demand);
- Water-related human health and well-being;
- Industrial activities (in particular, water uses of mining);
- Agricultural activities (in particular, the water uses of commercial and subsistence farming);
- Wastewater and its conveyance/collection and treatment;
- Potable water (including formal reticulation networks and water-treatment works supplying urban and peri-urban settlements, as well as informal access to drinking water);
- Environmental water requirements;
- Water use and overall water balance.
It is expected that the model will accurately portray the biophysical characteristics of the catchment and its reactions and interactions with social, economic and political drivers identified in the region. The quantitative simulation results will provide valuable insights into the complexities involved in water resource management with regards to managerial and infrastructure capacity development and compliance monitoring and enforcement activities.

ResiMod as a product of the SDM process will be used as a tool to facilitate learning and discussions between the participating stakeholders. It is envisaged that the model be used as part a social learning experience, where the impacts and effects of factors like climate change, different management strategies, policy interventions, maintenance and investment strategies are indicated to key role players within the system, to illustrate the value of systemic thinking. The outcomes of this study will further provide simulation results that can be used to inform stakeholders and policy makers across all sectors in order to approach and manage the Selati catchment in a way that will ensure water security (quality and quantity) to sustain ecosystems, livelihoods and economies.

**Keywords:** catchment management; ecosystem services; integrated water resource management; Limpopo; water security; water services.

**ACKNOWLEDGMENTS**

The authors would like to express appreciation for the support of the RESILIM-O programme, which is funded by the United States Agency for International Development under USAID Southern Africa – RFA-674-12-000016 RESilience in the LIMpopo Basin Program (RESILIM).
INTRODUCTION
The South African electricity utility, Eskom SOC, is currently undergoing a shortfall in generating capacity against a backdrop of increasing electricity demand, a problem that has inculcated in load shedding. This problem is exacerbated by the current state of Eskom’s ageing power stations and the need to perform scheduled maintenance, whilst retaining commitment to deliver on the new build program. If this maintenance is not done, power stations will continue to degrade and the unplanned capacity losses resulting from this degradation will worsen electricity supply constraints and furthermore, potentially result in safety risks. Undertaking the maintenance, however, means that specific power station units would be unable to generate power for the duration of the maintenance, again adding to supply shortfall.

A simulator was developed using the system dynamics methodology as outlined in John Sterman’s Business Dynamics to understand the complex interactions surrounding the balance between the need for maintenance, the need to supply electricity and the long-term impacts of short-term decisions.

Simulator development was undertaken using iSee Stella and an outage scheduling tool was successfully constructed. The simulation time frame was selected as 10 years, from 2015 to 2025, to run at a daily resolution. The simulator also needed to run on a “per unit” basis, modelling each generating unit at all the Eskom power stations, as these are treated individually when considering maintenance. This resulted in the simulator having to deal with 3650 days’ worth of data for 91 generating units, around 33210 data points in total. While iSee Stella is able to deal with this information, simulation time was slowed to roughly 10 minutes per scenario run and exporting data from Stella to Excel resulted in consistent system crashes.

In order to resolve this problem, the simulation development platform was migrated from iSee Stella, a traditional system dynamics tool using fixed structures (stocks, flows etc.), to Visual
Basic programming in MS Excel, a platform not traditionally associated with system dynamics at all.

INITIAL CHALLENGES

A key advantage for the use of Stella to simulate Eskom problems is the ability to create a user interface, allowing senior management, who would be unfamiliar with the modelling environment, to engage with the simulation and run scenarios.

Figure 1 shows how an interface page was constructed using MS Excel, with Visual Basic based macros programmed directly into the light-grey buttons. The user is also able to enter information into the blue cells, allowing some level of interaction and scenario analysis. This method does not produce interfaces which are as dynamic and user friendly as is the case with Stella, but it was a workable solution.

System dynamics simulation requires core concepts such as stock-flow dynamics to be observed. This is easy to maintain in specially designed software, but required direct care to be taken when programming in a different environment as specific cells had to be considered as stocks, equations relating to them being treated appropriately.
CONCLUSIONS

Moving from a programming background into a system dynamics frame simulation environment can be challenging as system dynamics simulation software does not afford the modeller the opportunity to use programming tools such as loops, functions and procedures. System dynamics software is intentionally designed around structure, if the stock flow structure has not been built appropriately, the simulation will not return reasonable results. This can prove to be both a challenge and a boon to modellers as while it can be difficult to resolve structural problems, inconsistencies between results and expectations point directly to problems with assumptions or structure, no time is wasted working through complex equations or code, rather the modeller can immediately begin revising his understanding of the system and adjusting the simulation accordingly.

The key value of a system dynamics simulation tool lies in the thinking and methodology required to construct a stock-flow feedback system which represents a complex system. Without the initial simulator development in iSee Stella, this thinking would never have been developed for the Outage Scheduling Simulator Tool discussed above, and the model could not have been completed with the required degree of functionality.

MS Excel does offer some benefits in terms of results visualisation. Figure 2 shows a graph generated by the MS Excel based tool where planned maintenance requirements are represented as stacked bar charts and available capacity for maintenance is represented as a red line.

![Figure 4 - Stacked Bar Chart View of Planned Maintenance](image)
In summary, while the specific aspects of this problem necessitated the use of a modelling tool not traditionally associated with system dynamics, it is not a methodology that this author would recommend as a standard, and in fact would not have been possible at all without first exploring a system dynamics tool.

**Keywords:** Eskom, Maintenance, System Dynamics, Project

**ACKNOWLEDGMENT**
Mpumi Motsoadi

**REFERENCES**
ABSTRACT

Theory on Sociotechnical System (STS) provides a framework to approach modelling and analysis of Command and Control (C2) systems. A STS consists of social and cognitive humans applying technology to perform work through a process within a social structure (organization) towards achieving a defined objective. Work can become complex due to dynamic and context dependent interaction between people, technology and the environment. STS tends to be developed through piecewise replacement of subsystems with new technology with the support of systems engineering. Systems engineering uses modelling to gain insight into complex systems and support answering questions on system requirements.

Modelling is used to explore structural, functional, and operational elements of the problem and solution space. Cognitive Work Analysis (CWA) and System Dynamics (SD) have been demonstrated as a modelling methodology for complex STS. CWA is a framework to analyze the way people perform work in an organization while taking the environmental constraints into consideration. The outputs of CWA are constructs that support modelling the structure and behavior of the system and environment. Functions provided by different technological elements are linked to the functional requirements of the system to achieve its purpose. However, CWA is limited in investigating the dynamic effect of decisions and policies on the system. The dynamic behavior of the complex STS can be analyzed with SD which uses the structure of the system for simulation. SD looks at the effect of feedback and delays on the operation of the system as a result of decisions based on policies.

The purpose of C2, as a force multiplier, is to bring all available information and assets to bear on an objective to ensure the desired effects through effective utilization of limited resources. C2 consist of planning an advantageous encounter with an adversary with appropriate resources at the right place and time. C2 processes and systems support humans in designing courses of action through problem solving within a military context and control their execution. Endsley defines
situation awareness as “the perception of elements in the environment within a volume of time and space, comprehension of their meaning and projection of their status into the near future”. Situation awareness is seen as a critical but elusive constituent for successful decision-making in complex and dynamic systems, such as military C2, nuclear power plants, air traffic control, emergency response and aviation.

This paper employs a SD model to investigate the effect of different variables on situation awareness through modelling and simulation. The situation awareness model and CWA constructs are used to support developing a CLD as seen in Figure 1. These models are the basis for identification of important variables and the causal relationships between them in the system. The elements in the Values and Priority Measures layer of the ADH provide guidance to identify the variables in the CLD. The Purpose Related Functions shows how the variables inter relate while the functional models indicate how the loops connect.

![Figure 1. Causal Loop Diagram.](image)

The structure of the SFD in Figure 2 is derived from the CLD with inputs from Endsley’s situation awareness model and Boyd’s OODA loop. The stock that flows through the model is “information”. Information is gathered, distributed, processed and displayed to support planning and decision-making. Variables are added to represent the external environment as well as to match the variables’ dimensions and units. Situation awareness also has a limited time value as it is affected by changes due to own force actions and the environment. The purpose of the SFD is to support simulations that assess the impact of the technology's different capabilities on the dynamic behavior of the whole system.
Modelling and simulation support learning about the system and the impact of a new technology on situation awareness. The insights gained from the modelling can support planning of experiments for measurement. Future work includes modelling the effect of different types of information with different delays and timespans. Monte Carlo type simulations may also be used to assess the relationships between the variables of the models.

This paper demonstrates how SD can be applied in support of a SE process. SD support learning about the problem situation that needs to be resolved through implementation of a new technology.

**Figure 2.** Stock and Flow Diagram.

**Keywords:** Command and Control; Cognitive Work Analysis; Situation Awareness; System Dynamics.

**REFERENCES**


Key Value Chain KPI Simulator

Naledi Memela*¹, Nalini S Pillay², Pieter Nortje³

¹, ² Technology Strategy and Research Management, Eskom: RT&D, South Africa.
E-mails: ¹Memelan@eskom.co.za, ²PillayNa@eskom.co.za
³ Enterprise Performance Management, Eskom, South Africa; Email: NortjePJ@eskom.co.za

BACKGROUND
This project is aimed at enhancing the current understanding of factors influencing business performance across Eskom’s value chain from Primary Energy and Generation to Distribution and Transmission, using a system dynamics (SD) methodology. Each division individually reports on and works towards a set of Key Performance Indicators (KPIs) targets which are quantifiable measures used to track business performance. The simulator highlights the extent of cross-divisional KPI influences on performance and provides an understanding of the interdependencies as well as the underlying driving forces.

MODELLING METHODOLOGY
The system dynamics modelling process included the development of a system architecture map (SAM) which is a high level process flow diagram of the Primary Energy (PED) and Generation (Gx) divisions. A model boundary chart (MBC) was completed to clearly define the boundaries of the system, listing all endogenous (outputs), exogenous (inputs) and excluded variables of the system. A causal loop diagram (CLD) was also developed to illustrate the causal linkages and direction of influence of variables within the system. These modelling steps were crucial in understanding the causality between the system variables and to establish the system modelling boundary.

The first phase of the project included modelling the integrated structure for Primary Energy and Generation divisions. In order to map out and include key driving forces for each division, subject matter experts were consulted for critical technical contributions, as well as for data validation purposes. PED consists of three key performance areas (KPAs); Coal Operations, Water Operations and Logistics. The KPAs included for Gx are the Technical and Environmental KPAs. Exclusions include safety and financial KPAs for both Primary Energy and Generation. The KPIs within these KPAs are reported in Microsoft (MS) Excel dashboards which are submitted to Executive Management on a quarterly basis. Stakeholder engagements were held
throughout the project lifecycle to interrogate the data and to discuss the calculation methods for the all the key performance areas. KPI targets from the Eskom 2015/16 Corporate Plan and PED business plan were built into the simulator for future performance targets. The simulator time frame runs from 2012 to 2019 on a monthly resolution, projecting from 2015 to the end of 2019. Historical data is built into the simulator from the year 2012 to the end of 2014.

**RESULTS**

Two situations will be discussed to illustrate typical scenarios that the simulator is able to generate. Firstly, the impact of varying coal calorific value (CV) rejection limits for all coal power stations. The user has the option to vary the coal CV value at each coal power station constrained by the station’s operational limits. The simulator then assesses the availability of the required coal and computes the coal consumption along with the corresponding coal costs and relative particulate emissions. These coal CV values obtained, along with other PED and Gx KPIs, are compared against the fixed KPI targets. Colour coded robots reflect the status of each KPI, indicating whether the target has been met or not.

In the second scenario, the simulator allows planned maintenance targets to be varied for each simulated power station. The impact on the availability, unplanned capability loss factor (UCLF), net production volumes (GWh) and energy reserve margin can be tracked and the overall system performance compared against Gx KPI targets. Figure 1 illustrates the simulated effect on coal consumption after an increase of 1MJ/kg to Coal Operating Unit 2 station’s CV rejection limit. It can be seen that an increase in coal CV results in a reduction in coal consumption.

![Figure 5: Actual Coal Consumption](image)
The simulator also assesses the impact of variation of the plant planned maintenance targets and the impact seen on the plant availability and energy sent out (GWh). Figure 2 illustrates the impact of decreasing plant maintenance targets across the coal generating fleet. The simulation indicates that decreased planned maintenance causes a reduction in the energy availability.

CONCLUSIONS

- A 5% increase in coal CV results in an 13.48% reduction in coal consumption.
- Decreasing planned maintenance by 2% from the baseline, causes a 1.78% reduction in the energy availability.
- These scenarios are selected examples illustrating the value and effectiveness of using a system dynamics methodology for sensitivity analysis. The simulator also has model structures which are linked to the PED Logistics and Water Operations KPAs as well Gx environmental KPA. These KPAs are all causally linked showing the impact of making changes to leverage points within the value chain.

**Keywords:** Extended Abstract, Key Value Chain KPI Simulator, System Dynamics.

ACKNOWLEDGMENTS

Danie Booyens, Corne Du Plooy, Priven Rajoo, Fulufhelo Makananise, Xolani Ngubeni, Chris van Alphen, Dr Willem Nel.
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Using System Dynamics to Minimise Operational Cost and Risk of a Stock Out of Returnable Transportation Stillages

Andries Botha

Senior Manager Logistics Planning, Toyota South Africa Motors Pty Ltd, South Africa, E-mail: abotha5@tsb.toyota.co.za

ABSTRACT

The spare parts business is an essential part of the original equipment supplier environment (Elhafsi, 2015) and even more so in an environment where servicing is critical to maintain warranties. Toyota Motor Corporation has defined “Contribution to a Low-Carbon Society” as one of its key focus areas. (Sustainability Fifth Action Plan: Toyota Motor Corporation, 1995-2015) One option to achieve a reduction in carbon emissions, is to reduce the reliance on one-way cardboard packaging and replace it with returnable transportation stillages. A supplier was approached to manage the process of supplying, cleaning and tracking the returnable transportation stillages. The objective of this study was to ensure that not only is the operational cost kept to a minimum, but the operational risk also managed.

The analysis proved to be a case of applying the authors key rules of business “What’s in it for me?” to both sides of the equation. As the supplier, being paid a rental fee for every day that the stillages are on-site, it is important to focus on ensuring that the risk of a stock-out be minimised by having sufficient stock on site, ready for use when called. While this reduces the risk of stock-outs, it increases the logistics cost and income for the supplier.

When the client asks the question “What’s in it for me?”, the answer shows important differences. While the justification for returnable stillages is the reduction of the carbon footprint, it does not mean that this must come at any cost. For the user, it is necessary that two objectives be achieved – low risk at a minimum cost.

A system dynamics simulation model was developed to develop a set of operational rules that would achieve the objectives of the client, namely: minimise both risk and cost. While traditional optimisation models fail when used in the supply chain environment (Alexander, 2014), the
The problem under investigation has two very specific reasons why a traditional optimisation model could not be used, namely:

1. Demand Variance
2. Constraint Mobility and Lead Time Variance

The demand is driven by daily variance in orders received from clients and executed on the same day. This means that it is not possible to accurately plan the demand for stillages in advance. There are also three types of stillages involved, resulting in increased level of complexity. Constraint mobility results when the constraining factor moves in and out of the process only being available during certain stages of the process. (This contrasts to a machine where there is stationary capacity – the capacity is there and visible during the full process. For example, an empty truck (mobile capacity) is part of the process, but the available capacity is not where it can be used.) In this case, the process lead time is also a variable with controlled and uncontrolled processes.

The simulation model was constructed to evaluate stock holding of stillages, stillage replenishment rules, as well as process lead time variables, within a real life demand domain. A series of rules and scenarios were analysed to develop an effective Service Level Agreement with the supplier.

By analysing the decision criteria scenarios and setting up the Service Level Agreement, it was possible to reduce cost and at the same time minimise the risk of a stock out. The key changes in the Service Level Agreement was to keep all excess stock at the supplier, ensure a two hour lead time for delivery of stock and to call stock to be replenished when an estimated two hours supply was left. The result was that transportation stillage stock on site was reduced by 60% (opening space for more effective operations), costs were reduced by 21%, without any increase in the risk of a stock-out.

The results show that by remembering the questions “What’s in it for me?” should be asked from both sides of the table.

**Keywords:** Supply Chain, System Dynamics, Returnable Transport Stillage, Risk Reduction, Operating Cost Reduction.
REFERENCES


Simulating the Chemical Usage of Power Stations Using System Dynamics

Mapule Minah Ntsoane\textsuperscript{1}, Nalini Sooknanan Pillay\textsuperscript{2} and Corne du Plooy\textsuperscript{3}

\textsuperscript{1,2,3} System Dynamics CoE, Eskom Research Testing and Development, South Africa. 
E-mails: \textsuperscript{1} Ntsoanmm@eskom.co.za, \textsuperscript{2} Pillayna@eskom.co.za, \textsuperscript{3} duplooyjo@eskom.co.za

ABSTRACT
Eskom’s power stations use a large bulk of chemicals such as sulphuric acid, caustic soda, lime, chlorine and ammonia for water treatment processes. The supply of these chemicals should be guaranteed and readily available since they are critical for the water treatment processes. These chemicals are used in the following processes:

- Sulphuric acid and caustic soda are used for the regeneration process of the demineralized (demin) water production plant.
- Cooling water treatment requires dosing of lime for softening the raw water and the pH is controlled by the addition of sulphuric acid.
- Ammonia is used to control the pH of the feed water (condensate from the polishers) whereas chlorine is used to produce potable water by disinfecting the micro-organisms from the filtered water [1, 2].

The objective of the project is to assess future trends for the consumption of the bulk chemicals, taking into considerations the causal linkages between the efficiency of the water treatment plant. This project aims to demonstrate scenarios for the chemical consumption quantity and costs depending on: the amount of demin water produced; the volume of cooling water treated; chemical dosing rates and the frequency of regeneration.

The key driving factors affecting consumption of chemicals includes, amongst others, the amount of demin water produced due to the regeneration process on the ion exchange vessels, the throughput of the demin water trains, the frequency at which contaminants are present in the feed water, as well as cooling water with regards to its turbidity and hardness [2, 4, 5].

A system dynamics methodology was followed and included the development of a causal loop diagram and a system architecture map that illustrates the main variables of the simulator that can be calculated within the model. The causal linkages between the demin water consumption and
consumption of sulphuric acid and caustic soda are calculated by the model. The higher the demin water demands for the station, the more frequent the ion exchange resin regeneration occurs which results in an increased demand for chemicals. Figure 1 shows the causal loop diagram developed for sulphuric acid and caustic soda. The causal loop diagram for ammonia, lime and chlorine are still under development.

The causal loop diagram consists of three reinforcing loops and one balancing loop as shown in Figure 1. Starting at the first reinforcing loop ($R_1$), if more demin water is produced, the run length of the trains will be less. The second reinforcing loop ($R_2$) illustrates the causality between the amount of chemicals required for regeneration and the run length of the demin train. The third reinforcing loop ($R_3$) shows the causality between the amount of demin water available and the station’s demand for demin water. The last loop is the balancing loop (B), which outlines the impact of a station’s demin water demand on the throughput of the demin trains.

The chemical projections can be completed by fitting a logistic (s-curve) equation to the historical data for the monthly demin water consumption, cooling water treated, potable water required, amount of feed water dosed.
The equation used to model the future trend of the consumption is shown in Equation (1).

$$Actual = U_0 + \frac{U_1}{1 + \exp[-C(t-t_0)]}$$  
Equation (1)

Where:  
$U_0$ – Initial value  
$U_1$ - Final values  
$t-t_0$ – Change in time  
$C$ - Growth rate that is calculated as outlined in Equation 2

$$C = \frac{2}{Duration} \ln \left( \frac{U-U_0}{U_0(\text{Error} - 1)} - 1 \right)$$  
Equation (2)

In both equations (1) and (2), the error of the projections could be minimised by varying the values of the limiting parameter and the initial time frame in order to fit the s-curve accurately to the historical data [6]. The fitting of the s-curve to the historical data allows for the projections to collapse at a maximum consumption rate as opposed to fitting linear regression equation to the data. The simulator can be used to determine the consumption for the various chemicals as they are utilised in different processes. The simulator displays results monthly for 120 months. The first 65 months is historical data and projections start from 66th time step. The simulator is still under development and the results obtained for the sulphuric acid and caustic soda require thorough validation.

**Keywords:** Caustic, chemical usage, lime, sulphuric acid, system dynamics, water treatment

**ACKNOWLEDGMENTS**
The authors would like to express appreciation for support from Talitha Koegelenberg, Nombuso Sibeko and Stephanie Marais.

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ABSTRACT

Understanding the process through which new ideas propagate through a population of potential adopters has been the focus of many research efforts. Of all the approaches and theories, the diffusion theory described by Rogers (2003) is widely used in application to many domains including Healthcare (Rogers, 2004).

Viewing adoption from a System Dynamics perspective has also been studied extensively. A simple model of diffusion of new ideas along the model introduced by Bass (1969) has extensively been used in System Dynamics literature (Sterman, 2000). In terms of Health Technology adoption Homer (1983) developed a comprehensive model consisting of 150 endogenous equations and 90 exogenous constants.

The problem with using the Bass model for analysis of adoption of Health Technology is that it is simply not possible to analyse enough of the dynamic parameters in the process. The Homer model, on the other hand is far too detailed to allow for investigative analysis of an adoption case, or to compare a dynamic parameter across a number of cases. This study therefore sets out to develop a System Dynamics model which is more specific than the former but less onerous to configure than the latter.

The method that will be used is to develop a conceptual model using a causal loop diagram (CLD) to represent the diffusion model described by Rogers.

Rogers (2003) defines Diffusion as “the process by which an innovation is communicated through certain channels, over time amongst the members of a social system”. He further assigns five stages to the process through which the innovation decision is made. This is illustrated in Figure 1;
Knowledge occurs when an individual is exposed to an innovation’s existence.

Persuasion occurs when an individual forms a favourable or unfavourable attitude towards the innovation.

Decision takes place when an individual engages in activities that lead to a choice to adopt or reject the innovation.

Implementation occurs when an individual puts the new idea to use.

Confirmation takes place when an individual seeks reinforcement of an innovation-decision already made.

Rogers also defines adoption as “a decision to make full use of an innovation as the best course of action available”

The causal loop diagram (Figure 2) that describes the innovation-decision process with the five stages as discussed above, was developed during a focus group discussion. The first 3 processes that summarise the “Adoption” sub-process is depicted in blue lines.

Figure 2: Conceptual CLD for Innovation-Decision Process.
In developing the above CLD into a representative conceptual Stock-Flow Diagram (SFD), it is useful to consider the sub-processes separately. Sterman (2000) describes the “adoption” sub-process in generic terms using Stock and Flow Diagrams (SFD). In order to account for some of the other elements in the Rogers innovation-decision process, additional influence needs to be added. Figure 3 below depicts the conceptual SFD for the adoption sub-process. For example: “gaining knowledge” represents the process through which potential adopters are transformed into “informed individuals”. Similarly, “getting interested” represents the process through which “informed individuals” are transformed into “interested individuals”. These additions allow for more specific manipulation of the key drivers in the adoption process that will allow for more detailed analysis.

The conceptual model based on the Rogers innovation-decision process can assist in developing a new System Dynamics adoption model which could allow for comparative analysis of various cases where available data and resources might not allow the application of more sophisticated models which have been described in the literature.

Figure 3. Conceptual SFD for the Adoption sub-process.

**Keywords:** Adoption, Diffusion of Innovation, Health Technology, Innovation-decision process, System Dynamics.
ACKNOWLEDGMENT

The authors would like to express appreciation for the focus group members who contributed valuable expert inputs to this study.

REFERENCES


A Conceptual Model for the Innovation-Decision Process with Focus on Acceptance

Getnet Bogale Fanta*1, Leon Pretorius2 and Louwrence Erasmus3

1, 2 Department Engineering and Technology Management, University of Pretoria, South Africa; Emails: getnetb@gmail.com, leon.pretorius@up.ac.za
3 Defense, Peace, Safety and Security, Council for Scientific and Industrial Research, Pretoria, South Africa; Email: lerasmus@ieee.org

ABSTRACT
An innovation needs to be coupled with a proper policy and a management approach to technology adoption and acceptance to facilitate the diffusion process and gain competitiveness in the market place. A focus group approach was used in this research to translate the five stage innovation-decision process model into Causal Loop Diagram (CLD) to identify the adoption and acceptance sections of the model. This study’s emphasis is on the technology acceptance section of the innovation-decision process. The elements that influence the acceptance of technology are gathered from the Technology Adoption Model (TAM). The Bass diffusion model is adapted to develop a stock-flow diagram (SFD) for the acceptance section of the innovation-decision process.

INTRODUCTION
Technology adoption and acceptance play a key role in the process of effective technology diffusion. The five stage innovation-decision process model incorporates the decision as well as the process of technology adoption and acceptance (Rogers, 2003). The adoption of technology can be at the institutional level or at an individual level; whereas, the acceptance of technology typically takes place at an individual level (Oliveira & Martins, 2011).

DIFFUSION OF INNOVATION
Venkatesh & Bala (2008) discussed two interventions in the process of technology adoption: pre-implementation that contains adoption, and post-implementation that includes acceptance.

Rogers (2003) described the innovation-decision process in five phases:

- Knowledge: learning about the existence, use and function of the innovation.
- Persuasion: forming a favourable or unfavourable attitude toward the innovation.
• Decision: individual chooses to adopt or reject the innovation.
• Implementation: putting an innovation to use.
• Confirmation: “the ultimate acceptance or rejection of the innovation” (Ward, 2013:225).

The first three phases of the innovation-decision process address pre-implementation interventions, i.e., the adoption decision process. The last two phases focus on the post-implementation intervention, i.e., the acceptance decision process. Adoption describes “organizational decision to adopt and implement a technology” (Venkatesh & Bala, 2008:292). Acceptance refers to “efforts undertaken to induce organizational members to commit to the use of technology” (Venkatesh & Bala, 2008:292). The result of the research in a focus group is illustrated in the CLD of technology adoption (blue lines) and acceptance (red lines) as depicted in Figure 1. This in essence reflects the resulting systems thinking process for the Innovation-Decision process.

Figure 1. Conceptual CLD for the Innovation-Decision Process.
ACCEPTANCE OF TECHNOLOGY

TAM is widely extended and empirically validated model, especially in the Information Technology (IT) sectors (Davis, 1989; Venkatesh & Davis, 2000 and Venkatesh & Bala, 2008). In the TAM model, Perceived usefulness and perceived ease of use were hypothesised to be fundamental determinants of user acceptance of Technology (Davis, 1989). Nevertheless, empirical studies indicated that perceived usefulness and behavioural intention to use directly determine the actual system use (Davis, 1989; Ward, 2013). The Bass diffusion model (Sterman, 2000) and TAM are used to develop the conceptual SFD of acceptance section of innovation-decision process (see Figure 2). Venkatesh & Davis (2000) indicated that the mandatory usage directly affects the intention to use in the early stages of technology implementation. The word of mouth (social exposure and imitation) has positive feedback or reinforcing influence on the actual users; whereas, adaptors saturation has a balancing effect limiting the number of potential adopters.

CONCLUSION

The five phase Rogers model for innovation-decision process address both adoption and acceptance. The SFD for technology acceptance incorporates the elements of the innovation-decision process and TAM. The acceptance section of the conceptual model of the innovation-decision process discussed in this study can serve as the starting point for further studies in the area of user acceptance.

Keywords: Acceptance; Causal Loop Diagram, Innovation-decision process; System dynamics; TAM.
ACKNOWLEDGMENT

The authors would like to express appreciation for the focus group members who contributed valuable expert inputs to this study.

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System Dynamics Constructs and Knowledge Management

John Trimble

Industrial Engineering Department, Tshwane University of Technology, South Africa; E-mail: trimbleja@tut.ac.za

ABSTRACT
Since the initial development of system dynamics (SD), knowledge constructs have been a major aspect of the field. This study is an ongoing effort to explore the development and utilization of knowledge and information constructs in system dynamics. The linkage between knowledge acquisition and these constructs is examined. Knowledge acquisition methods convert implicit knowledge (in mental models) to explicit knowledge embodied in SD constructs. Just as importantly, knowledge constructs utilized in the SD process provide decision makers, tasked with learning through the SD process, new knowledge. The current effort builds on earlier work by the author on knowledge acquisition and system dynamics (Trimble & Fey 1992). Over the years a number of system dynamics researchers have explored the linkage between SD and knowledge management. Azabadi et al (2012) uses “system dynamics to study the interaction between effective factors and structures of organizational knowledge management cycle including knowledge acquisition, knowledge creation, knowledge sharing, and knowledge utilization”. Saryazdi et al (2012) looked at SD for knowledge management in Iran, while (Wibowo and Waluyo 2013) linked SD, knowledge management, culture and performance in a case study of an Indonesian construction firm.

Knowledge management (KM) addresses: knowledge acquisition, knowledge creation, building a knowledge repository, accessing knowledge, and assessing the value of knowledge. Central to KM is knowledge representation. Knowledge constructs are the components of the KM system accessed by its users to assist them in making decisions. An effective knowledge management system must be able to evolve with changes in the organization and its environment, particularly with advances in technology. Knowledge management plays an increasingly important role in organizations. Many large organizations have Chief Knowledge Officers. Knowledge management is essential in addressing the complexity that is a natural aspect of all large systems and organizations.

KM and SD are simultaneously developing with the advances in information and communication technology (ICT). Computational power, remote access, expanded memory capacity, and improved human computer interfaces have impacted both SD and KM, enriching the expressiveness in each field.
SD is a critical paradigm for exploring and advancing the decision making process in complex situations involving feedback and delay. SD can be an important approach to developing learning organizations. This requires ongoing utilization of system dynamics models and thorough and assessable documentation of the outcomes of these modeling exercises. This can best be achieved with a comprehensive approach to knowledge management.

In the early state of the development of system dynamics it was called Industrial Dynamics. Forrester (1968 p. 406) points out “Industrial dynamics is a philosophy of structure in systems.” Forrester’s view is that structure has four significant hierarchies: the closed boundary, feedback as a basic system component, levels & rates, and the policy substructures. Each of these structures speaks to basic knowledge constructs. Early SD modeling relied on Dynamo and other text-based languages that had limited capabilities. This in turn limited SD knowledge constructs. Advances in SD in the 1980s included the development of icon-based languages such as Stella and iThink. This made it easier to document the stock and flow representation of SD models as well as graphical results. Over the years SD development tools have allowed for a range of advances in knowledge representation and knowledge sharing. Some of the SD knowledge structures that this project will address are the following:

- Stock and flow diagrams
- Causal loop diagrams
- Time horizons
- Reference modes
- Resource state tables
- Model boundary diagrams
- Subsystem diagrams
- Policy structure diagrams
- Bulls eye diagrams
- Model boundary charts
- Graphs of dynamic changes in key variables in the system
- Multi dimensional models using arrays
- Micro worlds
- Dashboards and flight simulators with multiple views and hyperlinks

Barnes and Milton (2015) points out “One of the biggest benefits of any KM system is making knowledge and experience available to the rest of the organization.” Most organizations are faced with a situation of information overload. To confront and deal with this situation there is a need to
systematically deal with the collecting, assessing and organizing of information and knowledge. The effective handling of an organization’s knowledge management system requires a regular reassessment of their approach to the generation and handling of knowledge. There have been different approaches to developing a dynamic strategy for knowledge management. As (O’Dell and Hubbert 2011) indicates, “The digital world has begun to reshape KM. Although new technologies always present new challenges, no KM function can ignore this opportunity”. Without a dynamic KM system the loss of critical knowledge is an ongoing organizational problem. Leonard et al (2015) reported that a survey of executives indicated that 97% responded yes when asked ‘Does your organization need to transfer business-critical expertise?’ and 78% indicated that loss of expertise is more of an issue now than it was five years ago. It is in this context that this study proposes to improve upon the use of SD in the knowledge management context.

The improvement will address two processes. The instructional or pedagogical approach to SD will be examined through the lens of several of the more popular textbooks used over the years to teach SD (Richardson & Pugh 1981, Wolstenholme 1990, Sterman 2000). Secondly, an effort will be made to develop a taxonomy or framework, to address the integration of SD knowledge constructs into a KM methodology. This will be built on previous efforts (Trimble & Keeling 2002, Trimble & Jenkins 2012) that focus complexity in knowledge management. Previous work (Lambe 2007) on constructing taxonomies of organizational knowledge is taken into account, particularly the effort to make taxonomies more accessible.

The intended outcomes of this project are: 1) a pedagogical style linking SD and knowledge management that will be useful in a number of courses; and 2) a framework addressing SD knowledge constructs that will aid the knowledge management process in a range of organizations. A starting point for constructing knowledge artifacts is the use of the interface option in Stella. This can be used to link various SD knowledge constructs, explanations and stories, using text, audio and video options. The use of the Stella interface option will be expanded and used as a pedagogical aid in both system dynamics and knowledge management courses. An assessment will be made of its effectiveness, which will be followed with recommended enhancements to the approach.

**Keywords:** knowledge management, taxonomy, knowledge constructs, knowledge acquisition.
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Exploring the Use of SD modelling Towards the Goal of Enhancing Resilience of People and Ecosystems in the Limpopo-Olifants Region of South Africa

J.K. Clifford-Holmes*1, W. Jonker2, T. York2, H. Biggs1 and S. Pollard1

1 Association for Water and Rural Development (AWARD), No. 14 Safari Junction, Hoedspruit, Limpopo, 1380, South Africa; E-mails: jai.clifford.holmes@gmail.com, biggsharry@gmail.com, sharon@award.org.za)

2 Department of Industrial Engineering, Stellenbosch University, South Africa; E-mails: 15608700@sun.ac.za; 16062221@sun.ac.za

ABSTRACT
Despite excellent legislative frameworks for water resource management and water service delivery in South Africa (SA), implementation continues to be affected by multiple constraints. The Association for Water and Rural Development (AWARD) has a 15-year history of undertaking action research in the Limpopo region of SA, within the context of deep capacity constraints that affect water resource management and water service delivery. The largest programme implemented by AWARD is called ‘Resilience in the Limpopo-Olifants’ (RESILIM-O) and is funded by the United States Agency for International Development (USAID).

The broad objective of the USAID: RESILIM-O programme is to improve trans-boundary management of the Limpopo River Basin resulting in enhanced resilience of people and ecosystems. This is addressed through:

1. Reducing vulnerability to climate change through improved water resource management;
2. Conserving biodiversity and ecosystems; and
3. Building stakeholder capacity to undertake and sustain (1) and (2).

The RESILIM-O programme is underpinned by systems thinking, stakeholder engagement and social learning (both in the conceptualisation and the research practices and management of the programme). This paper reports on the on-going system dynamics modelling (SDM) component of the programme, describing how an SDM process is underway in the form of a pilot study in one catchment of the Olifants.
The SDM process builds on earlier action research in the region, which explored the following:

- Water security and biodiversity;
- The relationships between water-related ecosystem services and human well-being; and
- The risks and vulnerabilities associated with different practices in each catchment.

This paper reports on the diverse modelling activities within the SDM process, which includes stakeholder engagement and the development of a ‘behind-the-scenes’ model. In the following section, the context of the pilot study in the Selati catchment is introduced ahead of the overall modelling approach being outlined.

The dominant land-uses in the Selati catchment are game ranching; dryland agriculture and rangelands; mining; urban settlements in villages and towns; and conservation, both within public parks (specifically the Kruger National Park) and private game reserves, such as the Selati Game Reserve (Pollard & Laporte, 2015). This combination of land uses is indicative of the broader Olifants basin, thus making the Selati an appropriate case for the pilot study for the SDM process. Central problems in the Selati pertain to ephemeral river flow, fluctuating water quality, basic access to drinking water, inadequate sanitation, management of wastewater, and reliance on natural resource harvesting. The governance and management dimensions of these challenges differ from the upper to the lower parts of the Selati, highlighting the need for catchment-level management and strategic planning.

The two main aspects of the SDM process are represented in Figure 1.

The stakeholder-engaged aspect of the modeling process (shown on the left-hand side of Figure 1) draws from existing ‘concept maps’, which were developed as initial systems pictures through multi-stakeholder workshops run between 2013 and 2014 by RESILIM-O team members. These concept maps are used as starting points for interacting with stakeholder groups to develop small models on a rapid-prototyping basis (Warren, 2014), developing what Ford (2009: 305) refers to as “a portfolio of models”. Rather than attempting to build one large model in the traditional Group Model Building format (Vennix, 1999), these small models are developed within individual stakeholder groups, in settings in which the stakeholders are at ease.
The primary stakeholder groups engaged in the process are the mining companies in the Phalaborwa region; eco-tourism and conservation authorities and businesses; municipal managers of waste-water treatment works; and communities using ecosystem services throughout the catchment. The second part of the process entails the development of a larger, SD-based model (called ‘ResiMod’), which is comprised of multiple sub-models (as visualised in Figure 1). ResiMod also draws from other biophysical modelling undertaken within the project, employing both qualitative and quantitative data. ResiMod will be used to explore different water security ‘futures’, with a particular focus on exploring what policies enable meeting water quality targets at the confluence of the Selati River and the Olifants River.\(^1\)

The overall aim of the SDM process is to utilise system dynamics as a tool to facilitate learning and discussion within the RESILIM-O project, and between the participating stakeholders and the RESILIM-O team, both in the model-building and the model use phases. As such, there is a strong

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\(^1\) ResiMod is described and discussed in the extended abstract of a second paper submitted to the 3\(^{rd}\) Eskom System Dynamics Conference.
focus on the modelling process rather than only on the outcomes. Modellers employed in the two main parts of the process interact with one another and the broader project team throughout the process, in order to ensure that the SDM component integrates into the overall RESILIM-O project. A final objective of the process is to use ResiMod for scenario planning and analysis in multi-stakeholder workshops in the Selati catchment (scheduled for between February and March 2016). This paper reports on the work to-date, discussing learnings and insights gained through the SDM process and how these will be carried forward into the next stages of the project.

**Keywords:** catchment management; ecosystem services; integrated water resource management; Limpopo; stakeholder-engagement; water services.

**ACKNOWLEDGMENTS**
The authors would like to express appreciation for the support of the RESILIM-O programme, which is funded by the United States Agency for International Development under USAID Southern Africa – RFA-674-12-000016 RESilience in the LIMpopo Basin Program (RESILIM).

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ABSTRACT
This project focuses on modelling the energy requirements for South Africa’s economic sectors using a system dynamics approach. The purpose of the project is to assist Eskom SOC in more effective long-term electricity planning for the growing future electricity demand due to the emerging socio-economic dynamics. Effective planning for future electricity demand of South Africa is essential to Eskom to avoid unserved electricity for its residents. Electricity demand is primarily driven by economic activity in the various economic sectors as well as by household consumption. Variation in demand for each sector is dependent on sector specific driving forces as well as technology factors that jointly form a complex system of interacting variables.

Simulations allow for an actual representation of a system and give users the ability to run scenarios to see the effects of deviation in key variables on the system, avoiding time consuming and impractical real-life experiments. The causal relationships between these variables are also more evident when making use of simulations. A system dynamics methodology was used to develop an integrated simulator that allows the user to perform sensitivity analysis on the changing energy demand of South Africa’s economic sectors.

The breakdown of the economic sectors being modelled is shown in the system architecture map in Figure 1. Due to data discrepancies, different modelling approaches had to be followed for some of the sectors. The four main approaches are as follow:

- **Baseline model**: Relevant short term energy consumption data as well as supporting studies were used to establish baseline behavior for the residential sector. Variation in future behavior can then be modelled based on the fundamental drivers for change.

- **Material flow analysis**: The model calculates the production volumes of material that flows through the different production processes of the sectors and the energy intensities...
required per production process. It then calculates total electricity requirements by multiplying the production volumes with the corresponding energy intensities.

- **Australian proxy model**: High resolution sectoral data from Australia was used to formulate a proxy model that was applied on a material flow bases to South African data. This approach was suitable because activity in the non-metallic minerals sector in Australia is similar to that of South Africa. The material flow analysis approach is used to develop a model which is then applied to South Africa, where material flows are known but not energy consumption.

- **Energy Accounting**: The remainder of the sectors’ energy requirements is calculated using econometric data to derive proportional statistics for energy consumption in different sectors under the assumption that proportional costs relate to proportional consumption. The sub-sectors were modelled as stand-alone models using iSee Stella software. They were then combined into an integrated economic sector model with GDP and population as exogenous inputs. The time frame for the simulator is 1993 to 2063.

Interfaces have been developed to facilitate simulated behavior in relation to variation across many exogenous variables including:

- GDP growth % of South Africa
- Population growth

Various scenarios can be run using this simulator, a few are listed below:

- Implementation of new technologies (type of technology and date of implementation)
- Amount of self- and co-generation by industries
- Implementation of carbon tax
- Political influences such as strike action or the nationalisation of mines
- Implementation of alternative energy sources (gas, diesel and petrol)
- Electrification rate of houses
- Rebound effect (e.g. heat more rooms because it is now more affordable to heat)
An example of a simulation interface is shown in Figure 2.

Figure 9: System architecture map for the integrated economic sector model

Figure 10: Technology improvements interface page for the non-metallic minerals sector
This page displays the total energy requirements for the non-metallic minerals sector, as well as the process heat requirements per product stream within the sector. Technology improvements can be implemented and this will result in changes to the energy requirements.

In conclusion, this integrated model will aid Eskom to plan more effectively for SA’s long-term electricity demand. Future research may include several refinements and changes (due to socio, economic, political and/or environmental influences) which could occur within the sectors. It is therefore recommended that both the model structure and data be revised in 3 years to assess whether the model still accurately simulates the electricity demand of South Africa’s economic sectors.

**Keywords:** Economic Sectors, Electricity Planning, System Dynamics.

**ACKNOWLEDGMENT**
The authors would like to acknowledge Alex Groenewald, Keith Bowen, Gina Downes, Nombuso Sibeko, Daniel Booyens, and SAPPI Ngodwana Mill for assisting with the project.

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ABSTRACT

I have been told that there are three ways to lose money:

- Horses – the quickest
- Ladies – the most fun
- Technology - guaranteed

This paper explores a fourth way:

- The Ponzi scheme – guaranteed to lose your money while you are firmly under the impression that you are getting seriously rich

A Ponzi scheme (named after Charles Ponzi who ran the first scheme in the 1920’s), exists when the operator promises you an unrealistically high returns over a short period of time. The scheme relies on new investors to pay off old investors. (South African Reserve Bank) The South African Financial Services Board indicates that a return more than 20% above the Repo Rate should be considered a pyramid scheme.

The objective of this study is to prove that the perception of wealth creation can be maintained for a sufficient period to pull in enough “investors” to allow the owner of the scheme to have a decent pay day when the scheme is wound down.

The study was done in three phases. In phase 1, the focus is on a single player Ponzi scheme. The question of how to achieve astronomical growth and generate a massive perceived investment pool is answered by assessing various investment strategies and interest rate domains. The longevity of the growth illusion is evaluated and the critical point, when to pack up and run, is identified.
In phase 2, the impact of fees is brought into play. The growth rates and longevity of the scheme is evaluated under conditions where monthly fees are payable. To ensure a comprehensive analysis, the differences between banking and Ponzi schemes are highlighted.

In phase 3, the true nature of the Ponzi scheme is revealed. Having proven that massive “returns” can be generated, it is now required that the Ponzi scheme be rolled out to potential investors. Based on the work in phase 1 and phase 2, the optimal investment strategy, interest rate domain and initial fee structure is defined. Please note, for the good operator, initial fees are not critical, as the main opportunity for making money is when the “fund” winds up and you stop taking calls from investors waiting for “returns”. Of course, if you specified your fees to equal the initial investment, with the investors getting all the returns, it should be perfectly legitimate to wind up the “fund” and take everything in the pot, as shown in the one person Ponzi scheme.

The key questions to answer in phase 3 are: How big should the potential market be? How much return should you guarantee? When do you wind down the “fund”?

While this analysis was done as a thought experiment, the reality is that the promises, if framed correctly, can be kept. The value created in the virtual space is significant. In the one man Ponzi scheme the illusion can be maintained long enough to tap at least half the invested money through fees before the investor will start asking questions about the true value of his investment base. As an investor, it is only possible to make real money if there are enough investors and you break the investment pact early enough.

Keywords: Ponzi Schemes, Investment, Returns.

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Working with Systems Thinking & Systems Dynamics when Linear and Convergent Thinking is the ‘Norm’

Marie McCrea

Partner CIL - Centre for Innovative Leadership; Ireland & South Africa; Email: marie@cil.net

ABSTRACT

In 2014, my organisation in collaboration with Dynamics Strategies (Andries Botha), was given the opportunity to make a proposal to a body of professional accountants to design a model that would help inform them about the future of the profession. Due to the confidential nature of the engagement I am not liberty to disclose either the client or details of the project.

We were faced with the opportunity to influence and inform traditional approaches and methodologies while at the same time providing the client with the required insights they sought. However with this opportunity also came the challenge of working against current methodologies and ‘wisdom’ in the field of model building.

It is the intent of this paper to share some of the insights gained from working across disciplines and how human behavior and our assumptions heavily influence our ability to learn.

I am myself a professional accountant by training and like many professions – engineering & law to name but a few, we were taught early on that problems were ‘solvable’ in our field if you took logical steps forward and followed the rule book clearly. We were not always encouraged or trained to look at the whole but to break the parts down. Rules and compliance to the rules informed most of our training. Many of us suffered and still do today when the set of rules don’t work once we try to influence a large system such as the organisation we are employed in or the one we are hired as a consultant to influence.

In the late ‘90’s I started to personally experience a frustration with my training and the competencies it had provided me with to really influence and change both myself and the organisations I was working with. It was at this time that I met Louis van der Merwe – founding & managing partner of CIL. He is not only a world recognized authority in the field of Scenario Based Strategy but also a Systems Thinker and both his work and the approach of CIL is founded on a systemic approach with both individuals and the organisations we work with.
Since then I have been ‘learning’ and applying and continue to learn and apply this uncommon yet more natural way of thinking. I have been privileged to have been trained in the basic principles of both Systems Thinking and Systems Dynamics Modelling but not only Louis but also Andries Botha. I have worked on projects with clients where this methodology forms the key component to our engagements and our ability to intervene with and support sustainable change.

So when the opportunity came to work with some colleagues in my profession to actually develop from scratch a Systems Dynamics Model I embraced it fully.

Some specific observations and challenges:
Recognition of Systems Thinking does not equate to understanding of it and/or application. It has been clear not only during this project but throughout my engagement with clients that individuals say they ‘get it’ but I believe this is partially human behavior not knowing the difference between recognizing something and deeply understanding it.

There appears to be a comfort with traditional modeling methodologies as they appear to give certainty and the apparent ‘logic’ appears easier to follow. Again human behavior comes into play in my opinion – there is an acknowledgement that these traditional models are not perfect, yet the change in thinking and approach required for a Systems Dynamics Model although accepted in principle are not actually accepted until experience shows the benefit of the alternative. As we engaged with the process and logic flow and the structural level of our design they continued to push back wanting to see ‘events’ level influencers in the model design. The natural instinct was to go to micro level economics and also event level measures/data points. I must admit this was a big learning point for me also as my accounting & business training as well as the way in which our media and economists continue to report influenced my own assumptions.

A further challenge was the ability of the system to accept the time frame historically over which a reliable model needed to be built to enable reliable scenarios and simulations for the future to be developed. Understanding the time line needed to get deep structural understanding of the influencers in a system was insightful.

Five times why? Well at minimum. It also became apparent that structural understanding was not natural within the system. Individuals working within the system had a perceived
understanding of how things worked and why. As we engaged for the ‘why’ it created some interesting push back and/or realization that they did in fact not know the answer.

Another key element to developing a reliable and calibrated model is supporting data within the organisation and or the market. This project highlighted not only the gaps within organisations on what they keep track of and for how long but also the quality and reliability and level of detail of the type of detailed market information required to develop the model.

Finally, once results were produced there was an automatic jump to taking the results produced from the simulation for future periods to be fact. Questions regarding reliability were raised rather than appreciating they represented one version of the truth. The continuous need to reinforce language and assumptions and purpose of the model was required.

We were fortunate due to the combination of competencies and experiences in our team to be able to find appropriate alternatives and assumptions to resolve some of the hurdles we faced during the project.

However, I believe the following must be considered by Systems Dynamics experts and emerging practitioners as they work with their existing and new clients.

Do not assume clients/end users understand even if there is recognition on the surface. Support their understanding using language and approaches which will encourage them to learn and engage and not turn them away. As with all fields, language gets in the way and we must continuously reinforce key messages, languages and principles of Systems Thinking first and foremost and then the modeling language if we are to build proficiency in this field. Capacity Building in these fields I believe is an essential part of the engagement for any client who has not worked in the field before. However, be aware that even though you recommend it – you may not succeed so there will be challenges as a result.

Acknowledge the natural discomfort of changing mental models and approaches. Although this approach may come naturally/instinctively to many in this room for others it has been a competence learnt. Continuous practice and engagement builds this competence and as practitioners I would encourage you all to not build technical barriers and/or look down upon those who ‘don’t seem to get it’ - give time.

Before engaging in a project I think the requirements to build a successful and reliable model need to be made clear. I would recommend that there are at least 2 persons involved from the
client perspective to share learning and build insights that will support the organisation/client after the experts have left.

Expect the unexpected. Even the best systems thinker and systems dynamics modeler is dealing with the largest uncertainty which is human behavior. Through this methodology I believe we can begin to breakdown some of the barriers in learning and at the same time build real competence in this uncommon yet ‘natural’ way of thinking and looking at the world.

**Keywords:** Linear, convergent, systems thinking

**ACKNOWLEDGMENT**

The authors would like to express appreciation to Andries Botha of Dynamic Strategies for the opportunity to present on the joint project and to Louis van der Merwe of CIL for the learnings & insights gained in this field and others within CIL over the years.
An Exploration of Gangs on the Cape Flats with Specific Reference to Gang-Related Murders using System Dynamics

Pieter Odendaal\textsuperscript{1,2}, Josephine K Musango\textsuperscript{2}, Alan C Brent\textsuperscript{3}

\textsuperscript{1,2} School of Public Leadership, and the Centre for Renewable and Sustainable Energy Studies (CRSES), Stellenbosch University, South Africa, josephine.musango@spl.sun.ac.za

\textsuperscript{3} Department of Industrial Engineering, and the Centre for Renewable and Sustainable Energy Studies (CRSES), Stellenbosch University, South Africa, Email: acb@sun.ac.za

ABSTRACT

Gangs are an important inhibitor of social cohesion. Reports suggest that Cape Town is South Africa’s deadliest city, with almost one gang-related death each day (Western Cape Department of Community Service, 2014). Between the year 2012-2013, 309 people were murdered in gang-related incidences, while 998 attempted murders were observed within this period; the conviction rate varies between 2-13% in some areas where gang activity occurs (Western Cape Department of Community Service, 2014).

Systems thinking and system dynamics has been used in various ways to investigate and explore the dynamic behaviour of gangs. Ruble and Turner (2000) have helpfully conceptualised urban street gangs as open systems with all the properties they entail. They defined street gangs as “groups of youths and young adults with varying degrees of cohesion and structure” (Ruble and Turner 2000: 117). Furthermore, Harris has identified gangs as a source of identity, self-esteem, status, identity and belonging (1994). Three kinds of gangs can be identified: social, delinquent and violent gangs (Ruble and Turner 2000). Social gangs are groups of young people who hang out together, without engaging in unprovoked acts of violence; delinquent gangs are more structurally organised and their activities revolve around “monetary gain derived from illegal activity” (Ruble and Turner 2000: 118.); violent gangs are those that seek to obtain power through violence. This third type of gang has a highly structured hierarchy with very specific roles to different members. Violent gangs are often plagued by both inter- and intragang violence (Lyon et al., 1992).

Ruble and Turner (2000) have compared gangs as open social systems to family systems, and applied concepts such as homeostasis, communication, boundaries, negentropy and entropy, subsystems and suprasystems and hierarchies, in order to understand the internal dynamics of...
gangs. We will not go into more detail here, but the important thing to note is the systemic similarity between gangs and families when trying to understand how gangs function and the consequent applicability of system dynamics modelling as a tool to approach questions about gangs.

Bridgewater et al. (2011) have found that most violent youth behaviour is attributable to gangs violence and that traumatic stress acts as a catalyst. The model that they developed considered that initial acts of violence may lead youth following a path of increasingly violent behaviour by through self-induced traumatization”. This violence feedback loop is crucial in understanding escalations of violence among and between gangs, and a simplified representation is shown in Figure 1.

“Slippery Slope Dynamics” refers to the movement of youths into gangs and their consequent entrapment in violent activities.

![Figure 1. Community Trauma and Affinity for Violence Feedback Loops](Bridgewater et al. 2011)

In a different study, Skarin et al., (2009) investigated cycles of gang behaviour by understanding both the social and economic influences that drive gang behaviour. They also explored various interrelationships between gang members, civilians and government. On the other hand, Choi (1999) developed a model to investigate urban youth homicide and the potential for reducing the amount of handguns that are available to youth in gangs.

Following Rubin and Turner (2000) definition of gangs, this study was limited to delinquent and violent gangs and investigated the dynamics of gangsterism on the Cape Flat. The study showed that, despite the complexity of the real-world system, it is possible to isolate some key elements of the system and to model their behaviour over time.
The study showed how an increase in the amount of time spent on policing gangsterism has a significant impact on both the number of gangster-murderers that end up in jail and the number of annual gang-related murders. Another key contribution from the result was the effects of the implementation of educational reform programs as leverage point in the fighting against gangsterism on the Cape Flats.

Despite some modest insights, the model can still be made more useful if more feedback loops could be incorporated into the structure. A very interesting future research possibility is to incorporate the socio-economic model of gangs developed by Skarin et al (2009) and the urban youth homicide model of Choi (1999) into the current model. This may result in a much more nuanced and complete picture of the system under scrutiny and it may highlight more interrelationships which exist between the elements of the system.

The current model has some weaknesses which should be addressed when taking the research further. One of the key assumptions was that each murderer murders an average of 2 people, whether they are civilian or gangsters, in order to calculate the amount of gangster-murderers by using the amount of murders as a proxy.

Some factors that were excluded include all non-homicidal gang-related convictions and imprisonments and the deaths of gangsters due to causes other than murder. Additionally, the model does not take into account the prevalence of murders that happen in jail.

All the above could be improved on when taking research further. Further, the collation of more data on the phenomenon of gang-murders on the Cape Flats will have to be a strategic priority in order to model the real-world system more accurately. This study is thus can be seen as a basis for continued research on gangsterism in the Cape Flats using system dynamics, in order to help and address a very complex socio-economic set of problems which have plagued the population of the Cape Flats for generations.

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Applying System Dynamics to Complex Social Challenges

R. Louw*1, Prof T. Igusa and Dr R. Biesenbach

1. Wits TCSE, University of the Witwatersrand, Johannesburg, SOUTH AFRICA; E-mail: rudolph.louw@wits.ac.za

2. JHU Systems Institute, Johns Hopkins University, USA; E-mail: tigusa@jhu.edu

3. Consultant, SOUTH AFRICA; E-mail: rbiesenbach@gmail.com

ABSTRACT

Following a visit to the Johns Hopkins Systems Institute by the Wits TCSE a collaboration in research with a focus on System Dynamics (SD) started. Wits teaches the world’s first SD course for medical / biomedical undergraduate students. Two major collaborative projects are being pursued, based on SD applications to complex social challenges and additional parallels in research are being formulated (e.g., urban renewal, obesity prevention).

The mission of the Johns Hopkins Systems Institute is to promote collaborative research and education activities in a new vision of systems. The overall goals are to enable Johns Hopkins and other collaborating institutions including Wits University, to engage in systems approaches to a wide range of grand challenge problems, and to create programs that will integrate research and education in systems science and practice of systems technology.

Current major initiatives include repurposing Pharmaceuticals: A Novel System Dynamics Approach; and Incorporating SD into the Development of Community Interventions. Future Work being explored could include collaboration in the prevention of obesity across Africa and HIV/TB management in South Africa.

The classical clinical trial sector is in trouble and urgently needs innovation and systemic renewal. Obesity is a global challenge requiring systems thinking. No country has succeeded in decreasing obesity outside of famine or war and HIV and TB management requires system solutions. So does diabetes, which will be the next great public health challenge after HIV/Aids, and cancer.

The mission of the Clinical Trial Systems Project (CTSP) is to recommend and develop progressive strategies for the US and potentially SA clinical trial system that would lead to rapid
and cost-effective access of pharmaceuticals for patients. Classical clinical trials are hugely expensive, risky and drawn-out as can be seen in Figure 1 below. The pharmaceutical industry today is in dire need of product and process innovation and the approach addressing drug repurposing is fast, inexpensive and less risky. A significant advantage of drug repurposing over traditional drug development is that since the repurposed drug has already passed a significant number of toxicity and other tests, its safety is known and the risk of failure for reasons of adverse toxicology are reduced.

**Figure 1. Funnel of drug development.**

SD principles and methodologies will be applied to study the repurposing process and will be used in future investigations, while prospective pilot studies will be developed and implemented with the same rigorous attention to patient safety and regulatory issues as traditional trials, then also used to validate the SD modelling for consistency. There will also be a strong emphasis on innovative Bayesian statistical design to enable faster identification or rejection of significance, supported by the SD models.

Figure 2 below depicts the SD flow that is followed in the repurposing project.
Obesity is ranked on par with very complex issues such as climate change and global water shortages. The overall prevalence of overweight (BMI >25) and obesity (BMI >30) in South Africa is high, with more than 29 percent of men and 56 percent of women being classified as overweight or obese. This is higher than that reported in other African countries, particularly in women, since nearly 30 percent of South African women aged between 30 and 59 years are obese. In fact, some describe the prevalence of overweight and obesity in South Africa as becoming an epidemic requiring an urgent and comprehensive approach.

South Africa has the largest longitudinal data sets on obesity (the Birth to Twenty data) - Fertile ground for system dynamics modeling the obesogenic environment in places such as Soweto - Exciting new research to be done soon and the South African data will be run on one of JHU’s computational platforms. New community interventions will be developed with SD principles and methodologies to provide crucial guidance to develop community interventions to tackle obesity and related diseases.

Using the Bt20 data to test hypotheses will see an existing SD model used to examine how the food environment causes weight gain in children. Environmental factors include the availability and consumption of various “obesogenic” foods such as soft drinks. This SD model would be calibrated using the Bt20 data and with the environmental (mostly household-level) data and after calibration, one would check this model using other populations in South Africa

**Keywords:** Abstract, Challenges, Complex, Social, System Dynamics
Author Biographies

JOSEPHINE MUSANGO

Dr Josephine K Musango is a Senior Lecturer at the School of Public Leadership (SPL), Stellenbosch University. She holds a Trans-disciplinary Doctorate in Sustainable Development and a Masters Degree in Agricultural Economics. She is responsible for the System Dynamics module in the postgraduate programme in Sustainable Development at the School of Public Leadership, and is a lecturer on the Renewable Energy Policy module in the postgraduate programmes of the Centre for Renewable and Sustainable Energy Studies (CRSES). Josephine’s expertise is in modelling for sustainable resource management and understanding complex socio-economic and environmental problems through application of economic analysis and system dynamics. For the last seven years, she has utilised system dynamics modelling in various contexts including resource flow analysis, aquaculture management, energy assessment, technology assessment and, recently, green economy modelling. She also has expertise in other modelling approaches including material flow analysis; agent-based modelling, discrete event modelling and Bayesian networks and econometrics.

NALINI SOOKNANAN PILLAY

Nalini graduated with an engineering degree at Wits University in 1994. In 1995 and 1996 she worked as a production engineer at Arcellor-Mittal, where she dealt with line expansion and optimisation projects. In 1997 she joined Eskom Research where she was involved in generation plant-related research, as well as the development of knowledge-management diagnostic programmes. From 2003 to 2007 she worked privately, and published several books. She re-joined Eskom Research in 2008 to project manage generation plant research activities and during this time developed a skills and gap analysis tool for knowledge management. She then got into system dynamics modelling and set up the System Dynamics Centre of Expertise at the end of 2011, while completing her masters in Sustainable Energy Engineering with UCT. She currently heads the System Dynamics CoE in Eskom RT&D and does ad hoc lecturing in Applied System Dynamics at various universities. She is also the vice-president and founding member of the South African System Dynamics Chapter affiliated with the International System Dynamics Society. She has published internationally recognised papers using a system dynamics modelling approach.
PROFESSOR DAVID RUBIN

David Rubin is an Adjunct Professor in the School of Electrical and Information Engineering at the University of the Witwatersrand, Johannesburg. He is currently the leader of the Biomedical Engineering Research Group and Director of the Undergraduate Biomedical Engineering Programme. He received his medical degree, MBBCh, from the University of Pretoria in 1986. After internship, he worked as a casualty officer and did various general practice locums before doing anaesthetics at Chris Hani Baragwanath Hospital, receiving his diploma in anaesthetics, DA(SA), in 1989. Following graduation with a Masters in Biomedical Engineering at the University of New South Wales in 1993, he returned to South Africa and Specialised in Nuclear Medicine. After qualifying as a specialist and receiving his Fellowship in Nuclear Medicine, he worked as a Nuclear Medicine consultant. In 1999, he left clinical medicine and joined Electrical Engineering at Wits where he started the Biomedical Engineering programme. David’s research interests include medical imaging, new modalities to treat cancer, and the application of systems theory to clinical and biological problems. He also initiated and led the development of a System Dynamics course specifically for medical students, making Wits the first university globally to formally incorporate system dynamics in the training of medical doctors.

DANIE BOOYENS

Danie holds a Bachelor’s degree in Mechanical Engineering from the University of Kwa-Zulu Natal and is currently completing a Masters in Sustainable Energy Engineering through UCT. Danie started working in the field of System Dynamics in 2012 as a member of the system dynamics centre of expertise in Eskom. He has since completed a number of simulation projects using this methodology and presented his work at various platforms including the first open colloquium of the South African Energy Modelling Network, the 3rd and 4th bi-annual coal stockpile forums and the 2013 International Conference on Energy Education. In addition to this, Danie has facilitated sessions on System Archetypes, Systems Thinking and System Dynamics Simulation at Stellenbosch University’s Sustainability Institute and at the University of Johannesburg.

CORNÉ DU PLOOY

Corné grew up next to the Vaal River in Parys, a small town in the Free State. From a young age he was always interested in science and maths and received a few project awards in these fields while still in school. After school he enrolled in chemical engineering at the University of North West, Potchefstroom Campus. During this time he and his team won first place with their heat exchanger design and beer brewing
projects. He completed his degree in 4 years and afterwards spent some time at the university where he was an assistant lecturer in Thermodynamics. In 2014 he started working at Eskom under the System Dynamics Centre of Expertise where he learned the principles of applying System Dynamics to solve modelling problems. He is currently still with the Centre as an Engineer.

MAPULE NTSOANE

Mapule Ntsoane was born in Limpopo Province and relocated to North West Province where she matriculated. After matric, she then studied chemical engineering at the University of North West, Potchefstroom Campus. She completed her degree in 2012 and joined Eskom Research, at the System Dynamics Centre of Expertise in June 2013. She is currently employed as an Engineer. Her interests in system dynamics started when she was completing her vacation training in March 2013. She has presented at the 2nd annual System dynamics conference and her paper on “Hydro pumped Storage simulator” has been published in the International System Dynamics Conference

ANDRIES BOTHA

Andries is a trained chemical engineer, with a Masters degree in the Management of Technology from the Massachusetts Institute of Technology and an MBA from the University of Pretoria. He has a passion for systems thinking and system dynamics, which he has applied to solving complex problems for a variety of clients. This includes focusing on the Toyota South Africa supply chain and vehicle distribution system. In 2007 he joined Toyota South Africa’s parts division as senior manager of logistics planning. Andries is an enthusiastic bridge player and a passionate Meccano collector.

ALAN BRENT

Alan holds bachelor degrees in engineering (chemical) and philosophy (sustainable development); masters degrees in science (environmental engineering), engineering (technology management), and philosophy (sustainable development); and a PhD in engineering management. Since 1995 he has consulted to a variety of sectors in South Africa and other developing countries in environmental engineering and management. He is currently at Stellenbosch University as a professor of engineering management and sustainable systems in the Department of Industrial Engineering, and as the associate director of the Centre for Renewable and Sustainable Energy Studies (CRSES). He is also appointed as a part-time professor of sustainable life cycle management in the Graduate School of Technology Management (GSTM), at the University of Pretoria.
TALITHA KOEGELENBERG

Talitha received a degree in B.Eng Industrial Engineering at the University of Stellenbosch in 2013. In 2014 she started her career at the System Dynamics Centre of Expertise, a section within Eskom’s Research, Testing & Development department in Johannesburg. During her time here she has had two papers published, one at the 2015 International System Dynamics Conference and one at the 2015 Industrial and Commercial Use of Energy Conference.

LEON PRETORIUS

Leon obtained his D Eng degree (1983) from the University of Pretoria, South Africa. He has more than 37 years of 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 the University of Pretoria. He has concurrently been active as specialist consultant and researcher in the engineering industry since 1980. He has supervised more than 170 masters and 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.

NOMBUSO SIBEKO

Nombuso Sibeko holds a bachelor’s degree in Electrical Engineering from the University of Witwatersrand (Wits). She started her career in Eskom Research and Innovation department under the generator and transformer section. Her focus was condition monitoring of generators and transformers and the integration of new technologies into Eskom. She won the Eskom managers and chairman’s awards for innovation in 2014 for her work in on-line shaft monitoring of generators. Nombuso joined the System Dynamics Centre of Expertise in 2014 where she has learnt the principles of system dynamics and system thinking and is pursing innovative ways to apply the SD methodology to assist with business decision support throughout the organisation.
MARIE MCCREA

Marie is a partner at CIL - Centre for Innovative Leadership. She is a seasoned international consultant of more than 15 years with proven skills and ability in supporting organisations in managing large scale change and transition projects through the use of scenario based strategy & systems thinking, as well as capacity building within these projects. She has a firm understanding of changing systems, through establishing improved behaviours and processes. She has a passion for quality and continuous improvement and brings her 17 years of employment experience in varying roles from the financial services and service industry as part of her portfolio. Her client portfolio includes South Africa organisations such as Eskom and the Chamber of Mines SA as well as New loveLife Trust. Internationally she has worked with blue chip organisations such as JP Morgan-Euroclear, DHL and Dresdner Kleinworth Benson. She is a Fellow of the Chartered Association of Certified Accountants (FCCA), certified as a Master Trainer by the Master Institute in Geneva and in team analysis by Belbin Associates. She is passionate about developing competencies and opportunities for all but specifically young people in the SADC region and is actively engaged professionally and voluntarily with such organisations and initiatives. This includes mentoring & supporting those studying and working in the accounting & finance profession.

NALEDI MEMELA

Naledi Memela was born in Durban, KwaZulu-Natal where he matriculated at St. Henry’s Marist College. He went on to study Chemical Engineering at the University of KwaZulu-Natal where he completed his degree in 2014. Naledi was first introduced to System Dynamics in 2013 as student undertaking vacation work. He is now currently employed at the System Dynamics CoE as an Engineer-in-training.

JAI CLIFFORD-HOLMES

Jai K. Clifford-Holmes is a Research Associate at the Association for Water and Rural Development (AWARD), based out of Limpopo, South Africa, where he works on a water-related project funded by the United States Agency for International Development (USAID). Jai recently completed his doctorate through the Institute for Water Research at Rhodes University. Since beginning his masters as a 2011 Mandela Rhodes scholar, Jai was part of a research team that employed a transdisciplinary approach to engaging seemingly-intractable water problems in South Africa (which included using system dynamics to explore the ‘modes of failure of local government’, in a collaboration with researchers from Delft University of Technology in the Netherlands). Jai is a
founding member of the South African chapter of the System Dynamics Society, and is serving on the interim policy council.

**JOHN TRIMBLE**

John Trimble is currently a Fulbright professor with the Industrial Engineering Department at Tshwane University of Technology. He recently retired from the Systems and Computer Science Department at Howard University in the USA. He conducted his doctoral studies in knowledge acquisition and the system dynamics methodology at the Georgia Institute of Technology in the Systems and Industrial Engineering Department. His current research involves knowledge transfer and appropriate technology.

**WILLEM JONKER**

Willem Jonker is originally from Johannesburg and has been living in Stellenbosch for the last seven years. He completed his BEng. Mechanical degree in 2013 and is currently in the process of completing a post graduate qualification in Engineering Management at Stellenbosch University. The focus of his research is on the role and effect of commercially producing biofuel in the Western Cape as part of the transition to a Green Economy. System dynamics was used extensively to simulate the possible outcomes of biofuel production in the Province and this model is a constituent to a larger model encapsulating the Western Cape Province’s transition to a Green Economy (WeCaGEM). After presenting some of the modelling work at the 2015 International Conference of the System Dynamics Society in Cambridge, Massachusetts, he was offered the opportunity to be part of a modelling exercise for the Association of Water And Rural Development (AWARD). The project aims to ultimately establish water security in the Limpopo Province through various stakeholder engagement processes, model building and social learning experiences.

**THEODORE YORK**

My name is Theodore York, I am currently completing my master’s degree in Engineering Management at the University of Stellenbosch in South Africa. My research focuses on the infrastructure implications of a transition to a green economy within the Western Cape, using system dynamics. I have a degree in Civil Engineering from the University of Stellenbosch and currently working on a the ResiMod project with AWARD (Association for Water and Rural Development).
RUDOLPH OOSTHUIZEN

Rudolph Oosthuizen joined the South African Air Force in 1990 as a permanent force member and obtained a B.Eng in Electronic Engineering from the University of Pretoria in 1994. In 1996, he completed a B.Eng (Hons) in Industrial Engineering and in 2002 a Masters in Engineering Management both from the University of Pretoria. In 2015 he received PhD also from the University of Pretoria in Engineering Management with the title “Modelling Methodology for Assessing the Impact of New Technology on Complex Sociotechnical Systems”. Over this period he fulfilled various systems engineering roles in infrared electronic warfare and command and control for the South African Air Force. In 2008 he joined the Defence Peace Safety and Security operating unit in the CSIR to continue supporting ground based air defence projects in command and control. The candidate has gained valuable experience in military systems and related systems engineering. He is currently in the service of the CSIR as a Principle System Engineer supporting various command and control related projects.

RUDOLPH LOUW

Rudolph currently is the Director of the Wits Transnet Centre of Systems Engineering, also holding the positions of Treasurer of the SA Heavy Haul Association as well as Member of the SA System Dynamics Association and was South Africa INCOSE Chapter President Elect for 2015. Rudolph has a B Mil (Physics), B Eng (Mech) Cum Laude and M Eng M degrees, completed Boeing strategic leadership courses at the Boeing Leadership Centre in St Louis, USA and successfully completed a number of other systems engineering and systems and project management courses. He was Director of the SA National Aerospace Centre; Executive Director of Boeing International for Eastern and Southern Africa; Managing Director of Analysis, Management & Systems and Manager at Armscor. He has been responsible for more than 200 projects, strategic Programme portfolios and establishing and developing partnerships around business and projects with more than a hundred organizations in 35 countries.

RIAAN(AJ) VAN DER WATT

Riaan(AJ) van der Watt has been active in the Health Technology environment in South Africa over the last 20 years. He started his career as a Mechanical Engineer but soon took up Biomedical Engineering and established and lead health technology departments at two of the large private hospital groups in South Africa. In 2007 he to start a consulting firm, focusing on delivering an independent service in the Health Technology Management arena. Riaan holds degrees in Mechanical and Biomedical Engineering and
a Masters in Engineering Management form the University of Pretoria. He is currently enrolled for a PHD in Engineering Management also at UP.