

DEPARTMENT OF DECISION SCIENCES

RESEARCH GROUPS

Title of the research group	Quantitative Finance
Research group leader	Professor HP Mashele
Members of the research group (full names)	- Prof. Mashele Hopolang, - Prof Mmboniseni Mulaudzi, - Prof. Safari Mukeru, - Dr Marc Mukendi Mpanda, - Prof Edson Pindza, - Dr Njengele Kenneth Kennedy Dukuza, - Dr Lebogang Sesale, - Dr Shivani Singh, - Dr Tlou Luzarus Kubjana
Research objectives	The research group in Quantitative Finance focus on studying and applying techniques from Stochastic Processes, Approximation Theory, Machine Learning, and Control Theory to better understand and address problems in the fields of Financial Derivatives Pricing, Portfolio Optimisation and Risk Management.
Keywords	- Stochastic Calculus - Volatility Modelling - Control Theory - Financial Derivatives Modelling - Portfolio Optimisation - Financial risk modelling - Financial Machine Learning - Market Microstructure - Algorithmic Trading
Catalytic Niche Areas	Fourth Industrial revolution and Digitalisation
Selected research outputs (10 max/ if available)	Umeorah, N., Mashele, P., Agbaeze, O. and Mba, J.C., 2023. Barrier options and Greeks: Modeling with neural networks. <i>Axioms</i>, 12(4), p.384.

Mpanda, M.M., Mukeru, S. and Mulaudzi, M., 2022. Generalisation of fractional Cox–Ingersoll–Ross process. *Results in Applied Mathematics*, 15, p.100322.

Mukeru, S., Mulaudzi, M.P., Nzabanita, J. and Mpanda, M.M., 2020. Zeros of Gaussian power series with dependent random variables.

Umeorah, N., Mashele, P. and Ehrhardt, M., 2019. Elliptical and Archimedean copula models: an application to the price estimation of portfolio credit derivatives. *Journal of Credit Risk*, 17(1).

Sonono, M.E. and Mashele, H.P., 2016. Estimation of bid-ask prices for options on LIBOR based instruments. *Finance Research Letters*, 19, pp.33-41.

Mukuddem-Petersen, J., Petersen, M.A. and Mulaudzi, M.P., 2014. Optimizing Basel III Liquidity Coverage Ratios. *Brygida Cullen (Hg.): Dynamic Programming and Bayesian Inference, Concepts and Applications: In Tech*, S, pp.67-90.

Petersen, M.A., De Waal, B., Mukuddem-Petersen, J. and Mulaudzi, M.P., 2014. Subprime mortgage funding and liquidity risk. *Quantitative Finance*, 14(3), pp.545-555.

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RESEARCH GROUP – CCRDS

Title of the research group	Computability, Complexity and Randomness in Decision Science
Research group leader	Safari Mukeru and George Davie
Members of the research group (full names)	Safari Mukeru, George Davie, Petrus H Potgieter, Delpont Terblanche (Department of Philosophy)
Research objectives	To analyse the interplays between probability theory and stochastic processes, algorithmic randomness, computability, and complexity and apply them to study fine properties of algorithmic stochastic processes.
Keywords	Randomness, complexity, computability, Brownian motion, algorithmic randomness, stochastic process
Catalytic Niche Areas	Innovation and capacity building in science and technology.
Selected research outputs (10 max/ if available)	1. Fouche, W.L. and Mukeru, S. On local times of algorithmically random Brownian motion. Theoretical Computer Science, 2023 2. Davie, G. Computability of convergence rates in the ergodic theorem for Martin-Löf random points, <i>J. Logic and Analysis</i>, 2022 3. Mukeru, S. Some applications of the Menshov-Rademacher theorem. (Comptes Rendus Mathématique, Paris, 2021). 4. Pauly, A. Fouche, W.L. Davie, G. Weihrauch-completeness for layerwise computability Logical Methods in Computer, 2018. 5. Mukeru, S. Representation of local times of fractional Brownian motion, Stat. and Probab. Letters, 2017.

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RESEARCH GROUPS

Title of the research group	Applied Mathematical Modelling and Decision Analysis Group (AMMDAG)
Research group leader	Edinah Mudimu
Members of the research group (full names)	Kenneth Dukuza Phumezile Kama Safari Mukeru Lebogang Sesale Diteboho Xaba Shivani Singh Nolwazi Nkomo Mmboniseni Mulaudzi Petrus Potgieter Swanepoel Christian
Research objectives	The Applied Mathematical Modelling and Decision Analysis Group (AMMDAG) focuses on employing a wide array of mathematical and statistical techniques to tackle complex real-world challenges. Our research encompasses the use of simulation, agent-based modelling (ABM), ordinary differential equations (ODEs), partial differential equations (PDEs), and nonstandard finite difference methods to model dynamic systems. We also utilize multivariable mathematical decision-making techniques, probability, and statistical methods, as well as stochastic control and optimization approaches. Our work spans diverse fields including public health, finance, health economics, and other critical areas, providing valuable insights and data-driven solutions for decision-making and policy development.
Keywords	Applied Mathematics, Agent-Based Modelling, Mathematical Modelling, Decision Analysis, Simulation, Ordinary and partial Differential Equations, Multivariable Decision-Making, Optimization Techniques, Dynamic Systems, Data-Driven Solutions, Health Economics, Interdisciplinary Research
Catalytic Niche Areas	Health Studies Natural Sciences Fourth Industrial Revolution and Digitalisation Energy
Selected research outputs (10 max/ if available)	1. Chazuka, Z., Mudimu, E. and Mathebula, D., 2024. Stability and bifurcation analysis of an HIV model with pre-exposure prophylaxis and treatment interventions. <i>Scientific African</i>, 23, p.e01979. 2. Moolla, H., Phillips, A., Ten Brink, D., Mudimu, E., Stover, J., Bansil-Matharu, L., Martin-Hughes, R., Wulan, N., Cambiano, V., Smith, J. and Bershteyn, A., 2023. A quantitative assessment of the consistency of projections from five mathematical models of the HIV epidemic in South Africa: a model comparison study. <i>BMC public health</i>, 23(1), p.2119. 3. Mpanda, M.M., Mukeru, S. and Mulaudzi, M., 2022. Generalisation of fractional Cox–Ingersoll–Ross process. <i>Results in Applied Mathematics</i>, 15, p.100322. 4. Amouzouvi, K., Assamagan, K.A., Azote, S., Connell, S.H., Fankam, J.B.F., Fanomezana, F., Guga, A., Haliya, C.E., Mabote, T.S., Macucule, F.F. and

	Mathebula, D., 2021. A model of COVID-19 pandemic evolution in African countries. <i>Scientific African</i>, 14, p.e00987. 5. Shatalov, M.Y., Surulere, S.A., Phadime, L.M. and Kama, P., 2021. Parameter Identification of Lorenz System with Incomplete Information: Case of One Unknown Function. <i>International Journal of Engineering Research in Africa</i>, 55, pp.82-102. 6. Dukuza, K.; Chaos in a discrete cancer model. <i>Journal of Applied Nonlinear Dynamics</i>, 11(2) (2022), 297-308.
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Research methodologies

The primary research methodologies employed in our research group are:

1. Agent-Based Modelling (ABM), which simulates the actions and interactions of individual agents to assess their effects on the system as a whole. This approach is primarily focused on exploring the impact of interventions on HIV transmission and management. The research integrates and analyses data from health surveys, household surveys, clinical trials, surveillance systems, and health records, including demographic data, health behaviours, adherence to treatment, and access to healthcare services. This data informs the model, detailing demographic specifics, health outcomes, human behaviour, and intervention efficacy. To ensure model accuracy, parameters are calibrated using historical data and validated against independent datasets. Sensitivity Analysis is applied to assess the robustness of the model by varying key parameters such as intervention uptake rates, adherence to treatment, and demographic changes. Additionally, Cost-Effectiveness Analysis (CEA) is utilized to evaluate the economic value of interventions by comparing their costs to health outcomes, aiding policymakers in efficient resource allocation.
2. Compartmental mathematical epidemiological models and other models in general, using the set nonlinear ordinary differential equations (ODEs). These models are not meant to predict the exact number of new cases of infection but are more suitable for investigating the role of certain parameters involved in disease progression, transmission, and any other dynamic properties of interest. Once this knowledge has been gathered, the next step is to decide which set of parameters to target to bring the disease under control or any system under investigation. Standard theorems of the field of dynamical systems, such as the Hartman-Grobman Theorem, Lyapunov Stability Theory, Chaos Theory, Centre Manifold Theory and so on, are the main tools of investigation and analysis.

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RESEARCH GROUPS

Title of the research group	Computational Intelligence and Data Science (CIDS) Research Group
Research group leader	Katherine Malan
Members of the research group (full names)	George Davie Kenneth Dukuza Phumezile Kama Tlou Kubjana Edinah Mudimu Safari Mukeru Mmboniseni Mulaudzi Lebogang Sesale Diteboho Xaba
Research objectives	Artificial intelligence (AI) is pervading many aspects of society and business with the result that individuals and businesses are becoming ever more reliant on AI to make decisions and achieve everyday tasks. Computational intelligence (CI) is a sub-field of AI that incorporates nature-inspired technologies such as neural networks and evolutionary computation that form the foundation of most recent tools in AI. The CIDS Research Group focuses on both fundamental research in CI technologies and applied research in the form of data science projects to address problems in the context of South Africa.
Keywords	Computational intelligence; Applied data science; Machine Learning; Evolutionary Algorithms; Search Landscape Analysis
Catalytic Niche Areas	Fourth Industrial Revolution and Digitalisation
Selected research outputs (10 max/ if available)	1. Riba, E.M., Malan, K.M. and Mudimu, E. (2023) Machine learning methods do have a place in univariate time series forecasting. In <i>Proceedings of the Fourth Southern African Conference for Artificial Intelligence Research</i>, SACAIR 2023, Muldersdrift, South Africa, December 2023, pp 70-83. 2. Bosman, I., Bosman, A.S. and Malan, K.M. (2023) Quantifying and Visualizing the Sharpness of Attraction Basins in Neural Network Error Landscapes. In <i>Proceedings of the Companion Conference on Genetic and Evolutionary Computation</i>, GECCO 2023, Lisbon, Portugal, July 2023, pp 2038-2046, https://doi.org/10.1145/3583133.3596322. 3. Liefoghe, A. and Malan, K.M. (2023) Adaptive Landscape-aware Constraint Handling with Application to Binary Knapsack Problems. In <i>Proceedings of the Companion Conference on Genetic and Evolutionary Computation</i>, GECCO 2023, Lisbon, Portugal, July 2023, pp 2064-2071, https://doi.org/10.1145/3583133.3596405. 4. Rodrigues, N.M., Malan, K.M., Ochoa, G., Vanneschi, L. and Silva, S. (2022). Fitness landscape analysis of convolutional neural network architectures for image classification, <i>Information Sciences</i>, DOI:10.1016/j.ins.2022.07.040 5. Malan, K.M. (2021). Online Landscape Analysis for Guiding Constraint Handling in Particle Swarm Optimisation, In: Kulkarni, AJ et al. (Eds) <i>Constraint Handling in Metaheuristics and Applications</i>, Chapter 5, Springer, DOI:10.1007/978-981-33-6710-4_5 6. Ochoa, G., Malan, K.M. and Blum, C. (2021). Search trajectory networks: A tool for analysing and visualising the behaviour of metaheuristics, <i>Applied Soft Computing</i>, 109, DOI:10.1016/j.asoc.2021.107492

	7. Malan, K.M. (2021). A Survey of Advances in Landscape Analysis for Optimisation, <i>Algorithms</i>, 14(2), DOI:10.3390/a14020040. 8. Mazibuko, T.C. and Malan, K.M. (2020). Machine Learning for Improved Boiler Control in the Power Generation Industry. In <i>Proceedings of the First Southern African Conference for Artificial Intelligence Research</i>, pp 148-161. 9. Mongwe, W.T. and Malan, K.M. (2020). A Survey of Automated Financial Statement Fraud Detection with Relevance to the South African Context, <i>South African Computer Journal</i>, 32(1): 74-112, DOI:10.18489/sacj.v32i1.777. 10. Malan, K.M. and Moser, I. (2019). Constraint Handling Guided by Landscape Analysis in Combinatorial and Continuous Search Spaces, <i>Evolutionary Computation</i>, 27 (2): 267-289, DOI:10.1162/evco_a_00222.
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RESEARCH GROUPS

Title of the research group	Mathematical methods and Applications
Research group leader	Shivani Singh
Members of the research group (full names)	Kenneth Dukuza Kerstin Jordaan Pretty Khambule Safari Mukeru Nolwazi Nkomo Shivani Singh Chris Swanepoel
Research objectives	Continuous and discrete mathematical methods serve as a cornerstone for studying the problems that arise in management, physics, engineering, and other sciences. This interdisciplinary research focuses on developing new mathematical techniques associated with special functions, integrability, graph theory, approximation theory, differential equations, and nonlinear equations.
Keywords	Continuous mathematical methods, Discrete mathematical methods, Special functions, Orthogonal Polynomials, Graph theory, Differential equations, Difference equations, Mathematical physics.
Catalytic Niche Areas	Other
Selected research outputs (10 max/ if available)	P Singh, S Singh, & V Singh. <i>Eigenvalue bounds based on projections</i>. Australian Journal of Mathematical Analysis and Applications, 21(1) (2024), 1-9. P A Clarkson, K Jordaan and A Loureiro, <i>Generalised Higher Order Freud weights</i>, Proceedings of the Royal Society A, 479 (2023), 20220788. P N Khambule, R Goswami, & S Maharaj. <i>Matching Causal thermodynamics of collapsing self-similar radiation shell</i>, International Journal Modern Physics D, 32(12), (2023) 2350080, 11. A S Jooste & K Jordaan, <i>On zeros of quasi-orthogonal Meixner polynomials</i>, Dolomites Research Notes on Approximation, 16(3) (2023) 48-56. K Jordaan, & M Kenfack Nangho, <i>Indeterminate moment problem associated with Continuous Dual q-Hahn polynomials</i>, Journal of Difference Equations and Applications, 29 (2) (2023) 165-180. P Singh, S Singh, & V Singh. <i>The Reich type contraction in a weighted $b v(\alpha)$-metric space</i>.

	Nonlinear analysis real world applications, 28(4) (2023), 2466- P Singh, S Singh, & V Singh. <i>Outer bounds for the extremal eigenvalue of positive definite matrices</i>. IAENG International Journal of Applied Mathematics, 53(2) (2023) 690-. P P Kar, K Jordaan and P Gochhayat, <i>Stieltjes interlacing of little q-Jacobi and q-Laguerre polynomials from different sequences</i>, Numerical Algorithms, 92 (2023), 723-746. P Singh, S Singh, & V Singh. <i>An efficient third order Mann-like fixed point scheme</i>. Nonlinear analysis real world applications. 27(440) (2022) 785-795. S Mukeru, & M P Mulaudzi. <i>On the inverse problem of fractional Brownian motion and the inverse of infinite Toeplitz matrices</i>. Journal of Physics Communication, 5 (202) 105020.
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RESEARCH GROUP – SOFT OR

Title of the research group	Soft Operations Research
Research group leader	CJ Swanepoel
Members of the research group (full names)	Any staff member whose research (or a specific research project) might not fit into one of the other groups.
Research objectives	To provide a space for research that takes the human element into consideration.
Keywords	Decision making; multi-criteria decision analysis (MCDA); physiological aspects of decision making; complex problems
Catalytic Niche Areas	
Selected research outputs (10 max/ if available)	1. J.C. Pauw & J.S. Wolvaardt: Multi-criteria decision analysis in public procurement – a plan from the South, Politeia, Vol 28, No 1, 2009. (This is a placeholder group for future use, once the Decision Lab is operational.)

Soft OR in Decision Sciences

Soft Operations Research (OR) is a branch of Operations Research that deals with complex problems that are difficult to model mathematically. It is important as a study field because it offers a way to address problems that are not well-behaved and cannot be solved using traditional OR methods. Soft OR methods are particularly useful in situations where there are many stakeholders with diverse views, and the problem is complex in nature.

Soft OR methods include techniques such as Soft Systems Methodology (SSM), Strategic Options Development Analysis (SODA), Scenario Planning/Analysis, Causal Mapping, Theory of Constraints, Benefits Modelling/Analysis, Multicriteria Decision Analysis (MCDA), and Delphi Methods. These methods provide decision makers with systematic help in identifying an agreed framework for their problem and making commitments to a series of actions. They are action-oriented and provide a pathway to act on the problem, rather than just defining it. MCDA, which has been taught in the Department of Decision Sciences for many years, is a key technique in Soft OR. It is used to model the decision making process in a structured and explicit way, taking into account the preferences of the decision-makers and the trade-offs between the criteria.

Soft OR fits into the broader field of Decision Sciences, which includes decision analysis, risk analysis, cost-benefit and cost-effectiveness analysis, constrained optimisation, simulation modelling, and behavioural decision theory, as well as parts of operations research, microeconomics, statistical inference, management control, cognitive and social psychology, and computer science. Decision Sciences provides a unique framework for understanding problems in industry and society and improving policies to address those problems by focusing on decisions as the unit of analysis.

Studying human behaviour during decision making, using eye tracking devices, for example, can provide insight into how decision makers focus their attention on different parts of a problem, and how this affects their decision making process. In the longer term, a Decision Laboratory equipped with multiple eye trackers can assist in discovering the complexities of social interaction and group dynamics during decision making in a group context. Other tools, such as physiological measures of stress, can be used to study how decision makers respond to different decision scenarios and how this affects their decision making performance.

Further insight into the decision making process can be gained by integrating findings from cognitive neuroscience and behavioural economics into the research. For example, *decision making biases* are systematic errors in the decision making process that can lead to suboptimal outcomes. Cognitive neuroscience can help us understand the neural mechanisms underlying these biases and develop interventions to mitigate their effects. Understanding the underlying mechanisms of *attention* is another way that cognitive neuroscience can contribute to research into better decision making.

Additional reading:

<https://www.theactuary.com/2022/01/28/decision-time-decision-science>

Excerpt:

Decision science is an interdisciplinary domain that brings together data science, machine learning and artificial intelligence, business context and subject matter expertise.

Crucially, decision science leads with the decision to be made, not the data or technology available. It also treats decision-making as a scientific process. Whether informed by data or intuition, decisions are built around hypotheses that can be tested, refined and improved.

While data science and programming languages are key enablers, decision science goes further. It recognises that current approaches create siloes and leave gaps between data and the people who make decisions. For example:

- Starting with the data, rather than the decision, can lead to insights that are not actionable, or that have limited value
- A lack of domain expertise leaves room for misinterpretation of data, or the ‘discovery’ of insights that are already well understood
- Data may be imperfect or even biased, meaning expert judgment plays an important role
- Data, and the insights it delivers, are not static; taking an agile and iterative approach can refine analysis over time
- Key business decisions are often made on a recurring basis, but results are rarely monitored in a way that ties those decisions back into day-to-day actions.

Increasingly, big tech firms such as Google and many fintechs are appointing ‘**head of decision science**’ roles to plug these gaps. The ability to gather data, experiment and model scenarios, monitor results, and feed that information back into the decision-making process is how businesses can transform their decision-making so that it meets modern demands and opportunities.

<https://citeseerx.ist.psu.edu/document?doi=fed96811b99ac87b518aae4b964161cd87b503d3&repid=repl&type=pdf>

Excerpt:

Soft Operational Research (O.R.) methods are crucial when many stakeholder views have to be taken into account and when the problem that you are being faced with is complex in nature. They can be used as a tool to help understand the issues at hand and provide a range of reasonable solutions in how to overcome them. This paper will attempt to build a general picture of Soft O.R. methods based on relevant literature, and what Soft O.R. offers to problem structuring.

<https://www.pnas.org/doi/10.1073/pnas.082081699>

Excerpt:

Models of complex systems can capture much useful information but can be difficult to apply to real-world decision-making because the type of information they contain is often inconsistent with that required for traditional decision analysis. New approaches, which use inductive reasoning over large ensembles of computational experiments, now make possible systematic comparison of alternative policy options using models of complex systems. This article describes Computer-Assisted Reasoning, an approach to decision-making under conditions of deep uncertainty that is

ideally suited to applying complex systems to policy analysis. The article demonstrates the approach on the policy problem of global climate change, with a particular focus on the role of technology policies in a robust, adaptive strategy for greenhouse gas abatement.

<https://www.1000minds.com/decision-making/what-is-mcdm-mcda>

Excerpt:

Multi-Criteria Decision Analysis (MCDA), also known as Multi-Criteria Decision-Making (MCDM), is about making decisions when multiple criteria (or objectives) need to be considered together in order to rank or choose between alternatives.