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ISBN 978-3-030-37280-4 ISBN 978-3-030-37281-1 (eBook)
https://doi.org/10.1007/978-3-030-37281-1

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Foreword by Daniel Adams

The successful provision of infrastructure for science, technology and innovation (STI) in South Africa is at three levels of engagement, viz. (i) government and policy level; (ii) the funding agency level; and (iii) the implementation level, at research-performing institutions. Adequate levels of funding and effective support and coordination at all levels are a prerequisite for establishing and maintaining research infrastructure (RI) platforms, which is a critical enabler to the knowledge triangle and a vibrant research ecosystem. Central to the provision of RI is the adoption of appropriate mechanisms geared towards enhancing partnerships between the public and private sectors, that aid the development of a vibrant STI ecosystem. The success to sustaining such vibrancy hinges on the development and retention of the scarce, yet highly skilled and trained scientists, operators, technicians, engineers and specialists. Such human resources must receive priority attention and investment in order to maintain research and development activities at the globally competitive level.

This book provides an overview of the STI landscape in South Africa and succinctly outlines how the provision of RI has the potential to play a catalytic role in the advancement of STI endeavours. In addition, this book acts as a useful resource to ignite collaborative discussions and strengthen partnerships with sister countries on the African continent through the sharing of good practices and learnings of the National Research Foundation and the Department of Science and Innovation (DSI), in the management of RI grants.

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Foreword by Clifford Nxomani

Science, technology and innovation is a key part of the national developmental agenda and has been identified as a driver for socio-economic transformation in South Africa. Essential to realising a transformed society is the need to strategically invest in STI and effectively implement programmes that support research excellence and human capacity development.

Research equipment and infrastructures play an important part in the STI value chain. Considering this imperative role, the South African government, through the DSI and the National Research Foundation (NRF), invests and coordinates RI platforms in support of the STI agenda. For example, the establishment of the South African Radio Astronomy Observatory (SARAO) consolidates South Africa's investments in radio astronomy, further reinforcing the country and the continent as a key player in the field.

Faced with limited financial, human and infrastructural resources, the regional coordination of research infrastructure is becoming particularly vital in Africa. This book is relevant to stakeholders with an interest in the investment and management of research infrastructure and equipment in Africa. In addition, the book showcases lessons, gaps and opportunities at the strategic and operational levels, for regional governments, research funding agencies and the scientific community.

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Preface

This book provides an overview of the building blocks necessary for managing, steering and guiding the establishment of a RI. It acts as a reference tool for RI investment, access and management at the academic, grants management, agency and policy level. This book is also useful for the research community, students, research-performing entities and the private sector who have a keen interest in understanding the approaches and opportunities linked to the establishment, maintenance and management of RI platforms.

Although RI investments over the past ten years have improved in South Africa, the system is still overwhelmed by challenges which not only require continued financial investments but also strong governance, skilled human resources, management and monitoring and evaluation structures. A holistic view of RI investment is presented in this book by mapping the granting cycles from a funding agency perspective. The strides undertaken and lessons learnt over the past decade within the science and technology sector in South Africa are further highlighted, while taking account a more dynamic and sustainable RI ecosystem in the future.

An emergent observation over the past decade, is that the investment into research equipment cannot be considered in isolation. Parallel investments in (i) human capital development, including the upskilling and training of the next generation of researchers; (ii) operational costs; and (iii) costs relating to sustainability which includes upgrades and maintenance, as well as building and/or renovating suitable physical infrastructures to house the research equipment, are critical for enhancing impact.

This book therefore provides a tool for the (i) development of STI policies that enable the provision of RI funding and (ii) the establishment and management of relevant RI funding instruments. Furthermore, this book defines the requirements for the sustainable management of research equipment across its life cycle and is structured as follows:

Chapter 1 provides an overview of how the investment in RI contributes to the realisation of a vibrant national system of innovation and also describes the South African higher education landscape, which remains differentiated. It further makes reference to the RI funding strategy of the National Research Foundation and maps the infrastructure requirements and investment across the innovation value chain.

Chapter 2 provides a contextual background to the approaches employed to investing in RIs. Subsequently, this chapter zooms into the approaches adopted in South Africa for the identification of categories of RI funding, with due acknowledgement to the principles of the innovation value chain.

Chapter 3 focuses on processes employed by public funding agencies in the awarding of RI grants across the granting life cycle, spanning the pre-grant award to post-grant award and project closeout phases.

Chapter 4 explores some of the conditions that are linked to RI grants, using the National Research Foundation as a case study. This extends to how RI grants will be used and the roles and responsibilities of the research institution at which the equipment will be housed. The tail end of this chapter presents some key considerations from ethical issues and intellectual property management, to data storage, usage and management.

Chapter 5 maps the skills required to optimally and sustainably manage research equipment. This chapter defines the scarce skills and qualifications that are critical for managing and maintaining research equipment. Central to this chapter is the development of a robust succession plan to ensure that the pipeline for the development of critical scarce skills is maintained.

Chapter 6 explores activities linked to monitoring and evaluation, from risk management to reporting, site visits and technical audits. This chapter also makes the proposition for establishing a database which will serve as a central repository for information relating to the investment in RI within a specific country.

Chapter 7 defines the essential elements for the sustainable management of RI, including the human resources required to manage and maintain research equipment; ensuring that the infrastructural requirements are addressed to support access by various users; as well as the data and financial management of research equipment.

The final chapter concludes by drawing on challenges and presenting recommendations based on the National Research Foundation's journey over the past decade in the management of RI grants.

In summary, the book provides guidance on the building blocks necessary for steering and guiding the establishment and management of RI frameworks from a South African perspective. The book will also be a useful resource for public funding agencies in Africa linked to the Science Granting Councils Initiative in sub-Saharan Africa (SGCI).

Pretoria, South Africa

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Sepo Hachigonta

Acknowledgements

- National Research Foundation under the leadership of Dr. Molapo Qhobela
- Dr. Clifford Nxomani, Deputy CEO: National Research Infrastructure Platforms (NRIP), National Research Foundation
- Dr. Gansen (Dorsamy) Pillay, Deputy CEO: Research and Innovation Support and Advancement (RISA), National Research Foundation
- Dr. Daniel Adams, Chief Director, Department of Science and Innovation
- Prof. Angus I. Kirkland, University of Oxford
- Prof. Jannie H. Neethling, Nelson Mandela University
- Ms. Georgiet Hammond, National Research Foundation

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About the Authors

Dr. Rakeshnie Ramoutar-Prieschl obtained her doctorate in business management and her master's in biotechnology. As an academic, she has lectured, tutored and mentored both undergraduate and postgraduate students. In addition, she has served on various committees including the National Science and Technology Forum Awards and the Nanotechnology Public Engagement Programme, and has served on various advisory boards and steering committees including the Centre for High Resolution Transmission Electron Microscopy. She is Member of the Executive Committee for the Organisation of Women in Science in Developing Countries and Chair of the Board of Trustees for Child Welfare South Africa. She previously led the research infrastructure (RI) portfolio for over 11 years, as a Director at the National Research Foundation. While at the NRF, she developed a number of policies, strategies and frameworks that has provided the foundation for establishing, nurturing and sustaining a number of RI platforms in the country. She has also worked in vaccine development and has held various management positions including working at the Desmond Tutu TB and HIV Centre. She currently is Head of Research Capacity Development at the University of Pretoria where she is accountable for the full portfolio of grant support and strategic interventions for early career academics (ECAs). She has been the recipient of numerous grants to develop and strengthen the track record of ECAs at the university.

Dr. Sepo Hachigonta holds a master's and a doctoral degree in environmental science from the University of Cape Town. He is currently Director of Strategic Partnerships at the National Research Foundation (NRF) of South Africa. His interests span a number of trans-disciplinary fields from environmental and agriculture systems, to research policy that impact the continent's science, technology and innovation landscape. He has extensive networks with over 20 countries on the African continent. This is evident by his contributions in developing system analysis expertise aimed at addressing current global challenges through various programmes such as the Southern African Systems Analysis Centre (SASAC), a multi-year initiative that takes cognisance multi-level system analysis capacity interventions and a comprehensive approach to policy-related activities in Southern Africa. Additionally, he has been instrumental in spearheading South Africa's participation in regional and international bodies including the Science Granting Council Initiative (SGCI), the International Science Council (ISC) and the International Institute for Applied Systems Analysis (IIASA). Prior to joining the NRF, he was Programme Manager at FANRPAN, a regional policy analysis network on food security and agricultural based in Pretoria.

Abbreviations

AGI	Access to Global Infrastructure
BAC	Bid Award Committee
BEC	Bid Evaluation Committee
BSC	Bid Specification Committee
CERN	European Organisation for Nuclear Research
CHPC	Centre for High Performance Computing
CoG	Conditions of Grant Award
Co-PI	Co-Principal Investigator
CPA	Consumer Protection Act
CPI	Consumer Price Index
CV	Curriculum Vitae
DHET	South African Department of Higher Education and Training
DIRISA	Data Intensive Research Initiative of South Africa
DSI	South African Department of Science and Innovation
ERM	Enterprise Risk Management
EU	European Union
FIB-SEM	Focused Ion Beam–Scanning Electron Microscope
GRI	Global Research Infrastructure(s)
GSO	Group of Senior Officials on GRIs
HCD	Human Capital Development
HDI	Historically Disadvantaged Institutions (or Individuals)
Hons	Honours Degree (Year 4, post a three-year undergraduate degree)
HRTEM	High-Resolution Transmission Electron Microscope
ICT	Information and Communications Technology
IP	Intellectual Property
IT	Information Technology
JCC	Joint Coordinating Committee
JINR	Joint Institute of Nuclear Research
KPI	Key Performance Indicator
LHC	Large Hydrogen Collider

M&E	Monitoring and Evaluation
M.Sc.	Master of Science
NCA	National Credit Act
NDP	South African National Development Plan 2030
NF	National Facility
NICIS	National Integrated Cyber-infrastructure Strategy
NMR	Nuclear Magnetic Reactor
NSI	National System of Innovation
OECD	Organisation for Economic Co-operation and Development
PFMA	Public Finance Management Act
Ph.D.	Philosophiae Doctor (Doctor of Philosophy)
PI	Principal Investigator
PPPFA	Preferential Procurement Policy Framework Act
R&D	Research and Development
RDI	Research, Development and Innovation
RED	Research Equipment Database
RI	Research Infrastructure(s)
SA	South Africa, the Republic
SA-GRID	South Africa GRID Computing
SALT	Southern African Large Telescope
SANReN	South African National Research Network
SARS	South African Revenue Service
SCM	Supply Chain Management
SDG	Sustainable Development Goals of the United Nations
SKA	Square Kilometre Array
STI	Science, Technology and Innovation
STISA-2024	Science Technology and Innovation Strategy for Africa 2024
TEM	Transmission Electron Microscope
UPS	Uninterrupted Power Supply
USA	United States of America
VAT	Value-Added Tax

Chapter 1
Background

Science, technology and innovation (STI) provides the bedrock that is essential to the economic growth of a country and can be considered as the quintessential ingredients for the establishment of a knowledge economy (Lee, Park, & Choi, 2009). As a result, considerable investments in STI are made by governments and industry, with the expectation that these investments will lead to social and economic benefits. Underpinning STI excellence is the availability and access to well maintained research infrastructures (RI) that facilitates the undertaking of leading edge research and the training of highly skilled specialists.

1.1 Why Invest in RIs?

Research infrastructures form a central and integral part of the STI ecosystem as depicted in Fig. 1.1. They provide a platform for the production of new knowledge and innovation. The European Strategy Forum on Research Infrastructures (ESFRI, 2018) notes that RI includes major scientific equipment and infrastructures, cyber-infrastructures (or ICT-based infrastructures), scientific collections, archives and structured information, and entities of a unique nature that are used for research.

According to ESFRI (2018) Research Infrastructure can be defined as the facilities, resources, and related services used by the scientific community for:

- *Conducting leading-edge research;*
- *Knowledge transmission;*
- *Knowledge exchange; and*
- *Knowledge preservation.*

R. Ramoutar-Prieschl and S. Hachigonta, *Management of Research Infrastructures: A South African Funding Perspective*,
https://doi.org/10.1007/978-3-030-37281-1_1

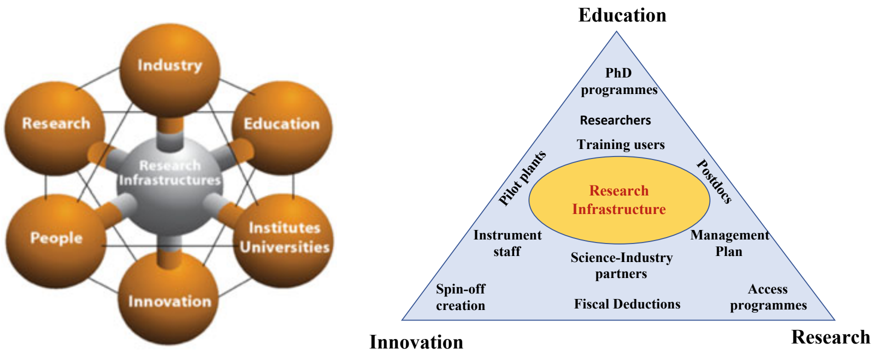


Fig. 1.1 RIs play a central and integral role in the research ecosystem

The motivation and process for investing in RI is informed by national STI strategies aimed at advancing scientific excellence within a country with the objective of finding novel and innovative solutions to socio-economic challenges. Such strategies therefore must align to international trends, policies and goals, such as the Sustainable Development Goals (SDGs) and the Science, Technology and Innovation Strategy for Africa 2024 (STISA, 2024). Intentions for investing in national RI vary based on a country's STI priorities. However, in principle, the goal can be described as follows:

- Supporting and promoting the development of innovative solutions that respond to national and global challenges such as food security, clean water and energy security, health, poverty alleviation, amongst others.
- Enhancing the quality of research undertaken by researchers, students, staff and emerging researchers through improved access to RI and equipment.
- Developing the technical and applications expertise specifically relating to the capacity for operation, maintenance and engineering support of leading edge research. This would contribute towards addressing the skills deficit not only in the country but also on the African continent.
- Inculcating a long-term planning culture relating to the management of research equipment. This inherently links to concepts of asset management, maintenance, support, training and the sustainable management of research equipment over its functional lifespan. Mechanisms must be in place for capital replacement and/or upgrade at the end of the equipment lifespan.
- Promoting regional, national and international approaches that collectively support the RI ecosystem.

1.2 The Innovation Value Chain

Innovation is an outcome of the dynamic interplay between a diverse array of stakeholders within complex systems that are interdependent, non-linear, and increasingly open and collaborative (Global Research Council, 2015). It involves an ecosystem of stakeholders from universities as well as the public and private sectors. Despite their varying investment foci, these stakeholders are able to collectively steer, shape and support the various stages of research, development and innovation. For instance, whilst public sector investments are primarily focused on basic research, as a driver for the development of highly skilled human capital and knowledge outputs, private sector investments are concentrated on the translation of knowledge that can lead to the development of an array of technological innovation, in the form of products, processes and services with direct commercial benefit.

There are essentially four stages in the innovation value chain that involve idea generation (basic research), idea development (applied research), idea testing (technology and prototype development) and the diffusion of developed concepts through commercialisation (Lee et al., 2009; Schot & Steinmueller, 2018). From an RI perspective, a holistic understanding of each phase and how this cumulatively impacts the innovation system is critical. Figure 1.2 gives a schematic example of the innovation value chain aligned to the RI sector. At this stage, it is important to note, that this process is not always linear, as a cyclical and reiterative process often ensues.

Basic Research is commonly defined as a systematic study directed toward gaining knowledge and new ideas or a better understanding of the fundamental aspects of phenomena without specific applications, processes or products in mind (Braun, 1998; United States of America, 2006). Basic research is usually designed to produce codified theories and models that explain and predict reality (Salter & Martin, 2001) and may have direct long term impacts. Basic research, also termed fundamental research or pure research, is an essential element of the innovation ecosystem.

Applied Research is unlike basic research as it is solution-or mission-oriented and aimed at addressing specific challenges that have direct societal benefit. This type of research is aimed at solving societal challenges through the development of innovative products, processes and technologies that impact the life, work, health and general well-being of people (Cherry, 2018).

Technology and Prototype Development Research is defined as a systematic application of knowledge or understanding, directed towards the production of useful materials, devices, and systems or methods. These include the design, development

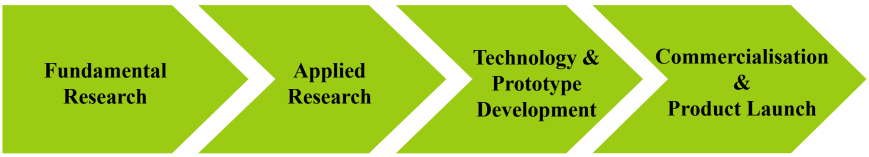


Fig. 1.2 Innovation value chain

and improvement of prototypes and new processes to meet specific requirements (United States of America, 2006).

Commercialisation and Product Launch: After the successful completion of the development phase, there is an upscaling of the full production facility and the innovative product, process or service is launched into the market where its commercial potential is realised.

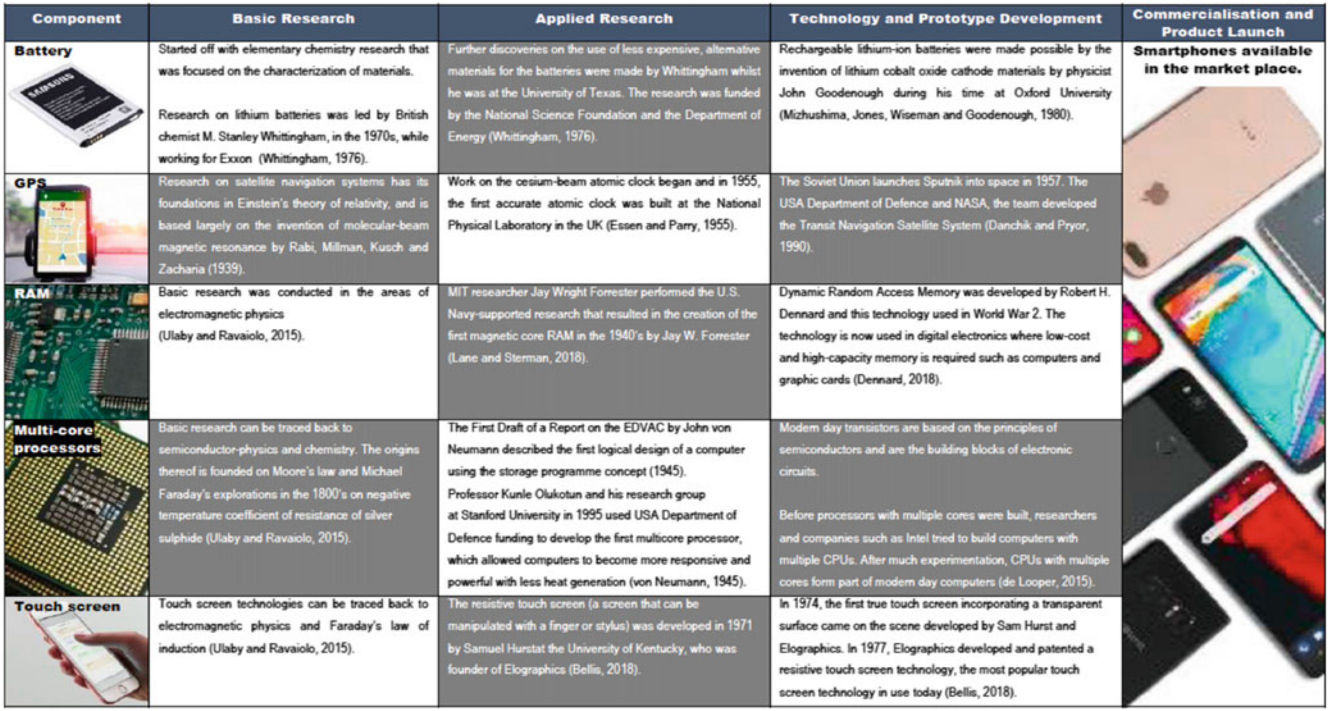
When looking at the innovation value chain, we can consider the example of the journey towards the development of the smart phone, as presented in Fig. 1.3, which comprises several components, i.e. (i) battery, (ii) GPS, (iii) RAM, (iv) multi-core processors, (v) CPU, and (vi) the touch screen.

Public and private sector partners, heavily invest in either a singular stage or multiple stages of the innovation value chain through universities, research centres, innovation hubs and other public research performing institutions. Despite the evidence that the investment in science may yield economic benefits, both direct and indirect (Fedderke, 2001; National Advisory Council on Innovation, 2004; Organisation for Economic Co-operation and Development, 2008; Salter & Martin, 2001), the return on the co-investments by both public and private sector partners has led to numerous contradictory arguments being presented. On the one hand, academics are renowned for (i) generating knowledge outputs in the form of publications, (ii) training students at various levels, and (iii) obtaining additional research capital. Industry partners, on the other hand, position themselves for increased market competitiveness through patents acquired, new or improved products, services and/or improved processes for new and/or enhanced product quality (Organisation for Economic Co-operation and Development, 2008). Compounding this challenge is the innovation chasm, which is underpinned on the theory of constraints. The consequential result associated with this challenge is the the low probability rates of translating academic research into marketable products, processes and/or services (Salter & Martin, 2001).

> "*Innovation in whatever form follows a power law: for every truly radical idea that delivers a big dollop of competitive advantage, there will be dozens of other ideas that prove to be less valuable. But that's no excuse not to innovate. Innovation is always a numbers game; the more of it you do, the better your chances of reaping a fat payoff.*" Hamel (2006)

In order to derive maximum returns from the STI investments from public sector, a holistic and well balanced approach that takes into account the entire innovation value chain must be considered. For instance, the Global Research Council (2015) identifies the following exemplars for strengthening the interplay between basic research and innovation.

- **Research underpins innovation and societal benefits**: A vibrant research ecosystem is essential to developing the talented individuals who will pursue curiosity-driven research as they respond to the world's pressing challenges and become leaders in the global knowledge and skills economy.



Component	Basic Research	Applied Research	Technology and Prototype Development	Commercialisation and Product Launch
Battery	Started off with elementary chemistry research that was focused on the characterization of materials. Research on lithium batteries was led by British chemist M. Stanley Whittingham, in the 1970s, while working for Exxon (Whittingham, 1976).	Further discoveries on the use of less expensive, alternative materials for the batteries were made by Whittingham whilst he was at the University of Texas. The research was funded by the National Science Foundation and the Department of Energy (Whittingham, 1976).	Rechargeable lithium-ion batteries were made possible by the invention of lithium cobalt oxide cathode materials by physicist John Goodenough during his time at Oxford University (Mizhushima, Jones, Wiseman and Goodenough, 1980).	Smartphones available in the market place.
GPS	Research on satellite navigation systems has its foundations in Einstein's theory of relativity, and is based largely on the invention of molecular-beam magnetic resonance by Rabi, Millman, Kusch and Zacharia (1939).	Work on the cesium-beam atomic clock began and in 1955, the first accurate atomic clock was built at the National Physical Laboratory in the UK (Essen and Parry, 1955).	The Soviet Union launches Sputnik into space in 1957. The USA Department of Defence and NASA, the team developed the Transit Navigation Satellite System (Danchik and Pryor, 1990).	
RAM	Basic research was conducted in the areas of electromagnetic physics (Ulaby and Ravaiolo, 2015).	MIT researcher Jay Wright Forrester performed the U.S. Navy-supported research that resulted in the creation of the first magnetic core RAM in the 1940's by Jay W. Forrester (Lane and Sterman, 2018).	Dynamic Random Access Memory was developed by Robert H. Dennard and this technology used in World War 2. The technology is now used in digital electronics where low-cost and high-capacity memory is required such as computers and graphic cards (Dennard, 2018).	
Multi-core processors	Basic research can be traced back to semiconductor-physics and chemistry. The origins thereof is founded on Moore's law and Michael Faraday's explorations in the 1800's on negative temperature coefficient of resistance of silver sulphide (Ulaby and Ravaiolo, 2015).	The First Draft of a Report on the EDVAC by John von Neumann described the first logical design of a computer using the storage programme concept (1945). Professor Kunle Olukotun and his research group at Stanford University in 1995 used USA Department of Defence funding to develop the first multicore processor, which allowed computers to become more responsive and powerful with less heat generation (von Neumann, 1945).	Modern day transistors are based on the principles of semiconductors and are the building blocks of electronic circuits. Before processors with multiple cores were built, researchers and companies such as Intel tried to build computers with multiple CPUs. After much experimentation, CPUs with multiple cores form part of modern day computers (de Looper, 2015).	
Touch screen	Touch screen technologies can be traced back to electromagnetic physics and Faraday's law of induction (Ulaby and Ravaiolo, 2015).	The resistive touch screen (a screen that can be manipulated with a finger or stylus) was developed in 1971 by Samuel Hurstat the University of Kentucky, who was founder of Elographics (Bellis, 2018).	In 1974, the first true touch screen incorporating a transparent surface came on the scene developed by Sam Hurst and Elographics. In 1977, Elographics developed and patented a resistive touch screen technology, the most popular touch screen technology in use today (Bellis, 2018).	

Fig. 1.3 Example of smart phone technology that has passed the various stages of the innovation value chain

- **Collaboration and dialogue is critical within the innovation ecosystem**: Linkages between publicly funded research organisations and industry may result in information and knowledge exchange that can inform the direction of research, allocation of investments, and the quality of innovation outcomes.
- **Evaluate impact**: Great attention should be given to the respective time frames of research, industry and other societal spheres. The methods used to judge success determine how research is monitored, evaluated, valued and funded, and how risk is perceived and acknowledged as part of the process.
- **Strengthen intra-regional cooperation**: Connectivity and collaboration at a regional level should recognise regional challenges and values whilst enhancing the opportunities for increasing the relevance of research and the outputs from the research and innovation process.
- **Nurture talent and enhance skills development**: Researchers and trainees who are internationally mobile, who work at the interface between disciplines, or who acquire work experience outside of academia, enlarge and strengthen the innovation system by facilitating knowledge transfer, diversity of viewpoints, cultural adaptation, and entrepreneurship.

1.3 An Overview of the STI Policy and Strategy Landscape in South Africa

This section builds on the provisions of the Research Development and Innovation Funding Framework that was developed by the Department of Science and Technology (DST) in 2010 (South African Department of Science and Technology, 2010). It maps the key policy milestones within the South African historical STI journey, which starts at the time of democracy in 1994, when a National Research and Development audit was undertaken. The key findings were that South Africa was still lagging behind other developing nations competing and collaborating in international research programmes, and that new financing for large research and development (R&D) equipment was a critical success factor for South African scientists to be globally competitive (South African Department of Arts, Culture, Science and Technology, 1996). Several policy frameworks and concept documents were subsequently developed with the objective of proposing interventions for improving the capacity to undertake competitive research and training by investing in human capital development and the procurement and upgrade of RI.

In 1996, South Africa's White Paper on Science and Technology was developed which focused on three pillars of investment: (i) innovation; (ii) science, engineering and technology, with a strong focus on human capital development and transformation; and (iii) creating an effective national science and technology system. The paper highlighted the need for highly specialised infrastructural platforms such as national research facilities to undertake cutting edge scientific research. The White Paper further made provision for the purchase and maintenance of expensive research equipment on the basis that:

- The placement of research equipment facilitates access to the wider research community with a specific focus on closing the gaps in the differentiated higher education landscape in the country.
- The research equipment is placed at a research institution with high achieving researchers in a specific discipline which will be advanced as a consequence of the placement of the equipment.
- The research institution co-invests in the procurement of the research equipment (South African Department of Science and Technology, 2010).

In 2002, the National R&D Strategy for South Africa was published, articulating the following pertinent recommendations:

- Scientific instrumentation is important for advancing research, economic growth and human capital development.
- Modern, well-maintained equipment is a pre-requisite for high quality research.
- Equipment has considerable economic impact, particularly in the manufacturing sector.
- The use of equipment in the educational sector is a key success factor in nurturing curiosity-driven research, and developing the requisite skills for undertaking world class research and supporting the advancement of modern industry (National Research Foundation, 2004; South African Department of Science and Technology, 2002).

In 2010, the Research, Development and Innovation Infrastructure Funding Framework was developed that identified five investment areas: (i) scientific equipment; (ii) high-end infrastructure; (iii) specialised facilities; (iv) access to global infrastructures; and (v) cyber-infrastructure (South African Department of Science and Technology, 2010). Critical to these areas of investment is the (i) management and access to large data sets that are produced or collected from research equipment; (ii) the exploitation and/or re-use of that data for enabling other fields and/or areas of research to be explored; and (iii) skilled operators, technicians and engineers to maintain and optimally utilise cutting edge research equipment (South African Department of Science and Technology, 2010).

In 2012, the National Development Plan (NDP) was launched with the objective of eliminating poverty and reducing inequality in South Africa by the year 2030. This would be achieved by (i) drawing on the energies of the people; (ii) growing the economy; (iii) building capabilities; (iv) enhancing the capacity of the country; and (v) promoting leadership and partnerships (South African National Planning Commission, 2012). The NDP embraces the concept of the triple helix whereby government, universities and the private sector aid in the translation of basic research into commercially viable products, processes and services. It further identifies STI as a primary driver of economic growth, job creation and socio-economic reform (South African Department of Science and Technology, 2019). Integrally linked to this driver, is the provision of research infrastructures that form a critical enabler for developing an equitable STI landscape in the country.

> *"R&D has played an important role in helping middle-income countries such as South Korea advance to high-income status. While South Africa needs to spend more on R&D in general, the institutional set-up also needs to improve the link between innovation and the productive needs of business. Government should partner with the private sector to raise the level of R&D in firms. Public resources should be targeted to build the research infrastructure required by a modern economy in line with the country's development strategy."* (South African National Planning Commission, 2012).

In 2016, the South African Research Infrastructure Roadmap (SARIR) was launched with the objective of providing a framework for the provision of the research infrastructures necessary for a sustainable national system of innovation (Pandor, 2016). This roadmap articulates the commitment of the South African government to research infrastructure development in the country. The investment in SARIR expresses a deep understanding of the importance of excellent research infrastructure as a critical enabler for undertaking excellent research. The roadmap identifies 13 potential investments of interest in RI in South Africa that are classified according to thematic areas. The investment in the 13 RIs must be viewed holistically and not in isolation from each other as there are a number of shared experiences, learnings, outputs and solutions that can be gained (South African Department of Science and Technology, 2016) (Table 1.1).

In 2019, a White Paper on Science and Technology was developed, that lays out the long term policy approach of the STI sector and emphasises the core themes of (i) inclusivity; (ii) transformation; and (iii) partnerships. The White Paper continues to expand the investment in research infrastructures, cyber-infrastructure and access to global research facilities. It also reviews the achievements and milestones since 2002, in a manner that creates a learning platform for sharing experiences, lessons, outputs and solutions (South African Department of Science and Technology, 2016). Whilst the White Paper builds on the successes and lessons since 1996, it also proposes and adopts new approaches to nurture creativity, learning and entrepreneurship. The key objective is to actively contribute toward the targets set forth in the NDP (South African Department of Science and Technology, 2018).

A summary of the above-mentioned policies and strategies, informing the investment in RIs over the past 25 years is presented in Fig. 1.4.

Table 1.1 Summary of the RIs identified for funding in the SARIR (South African Department of Science and Technology, 2016)

RI Domain	Identified RI
Human and social dynamics	The South African Network of health and demographic surveillance sites
	National Centre for Digital Language Resources (NCDLR)
Health, biological and food security	Distributed Platform for "Omics" Research (DIPLOMICS)
	Biobanks
	Nuclear medicine
Earth and environmental	A South African marine and antarctic research facility
	Biogeochemistry research infrastructure platform
	An expanded national terrestrial environmental observation network
	Shallow marine and coastal research infrastructure
	The natural sciences collection facility
Materials and manufacturing	Materials characterisation facility
	Nano-manufacturing facility
Energy	Solar research facility

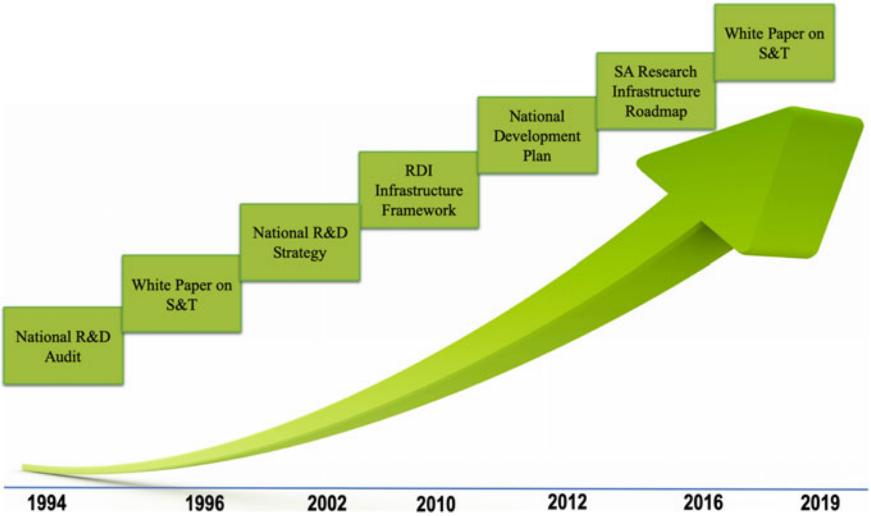


Fig. 1.4 An illustrative timeline representation of the key policies and strategies framing RI investments in South Africa

1.4 Role of the Funding Agency in the STI Policy Landscape in South Africa

Public research funding agencies are quasi-public organisations mandated by specific national legislative acts or laws. Although they are independent entities, they are still dependent on government for financial resources. Through the resources they manage, funding agencies play a central role in driving research and human capacity development programmes that meet specific requirements and criteria through the use of grant awarding processes to encourage research productivity from recipients of grants (Braun, 1998). Funding agencies can, therefore, be considered protagonists in the distribution of public resources and structure the way research is conducted by the stipulation of criteria and conditions linked to research grants (Braun, 1998). Research funding agencies also play a key leadership role in stimulating interest in young people to pursue careers in science and technology and developing a diverse labour force with the necessary skills to navigate in a knowledge economy (Lee et al., 2009).

The National Research Foundation (NRF) is the public funding agency in South Africa that was established as an independent government agency in 1998 (South Africa, 1998). The role of the NRF in the national context is summarised in Fig. 1.5. The mandate of the NRF is to contribute to national development by: supporting, promoting and advancing research and human capital development, through funding

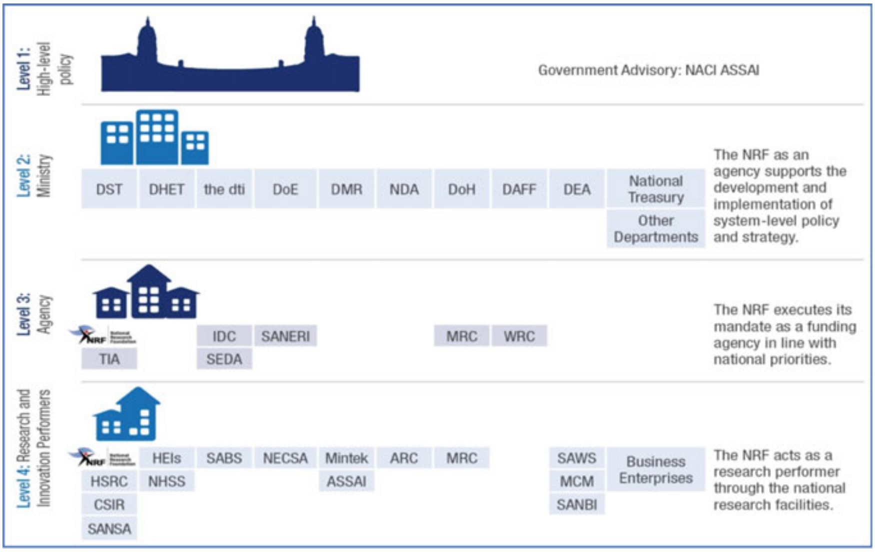


Fig. 1.5 The NRF within the South African research ecosystem (National Research Foundation, 2015)

and the provision of the necessary research infrastructure, in order to facilitate the creation of knowledge, innovation and development in all fields of science and technology, including humanities, social sciences, and indigenous knowledge; developing, supporting and maintaining national research facilities; supporting and promoting public awareness of, and engagement with, science; and promoting the development and maintenance of the national science system and support of Government priorities (South Africa, 2018). As such, the NRF, is responsible for the awarding of public funds utilising competitive review processes to public research performing institutions, including, but not limited to (i) universities; (ii) science councils; (iii) research laboratories; (iv) research hospitals; (v) research museums; and (vi) national research facilities, amongst others. Much of the content of this document draws on the processes and policies of the NRF.

1.5 Navigating a Differentiated Higher Education Landscape

To speak of a single, homogenous higher education system 25 years post-democracy would be painting an idealistic perspective with no consideration afforded to the social injustices and legacy left behind by the Apartheid regime (Mekoa, 2018; Reddy, 2004). The different types of universities under the new democratic government are still plagued by issues such as (i) unequal funding; (ii) skewed demographic profile of students and staff; (iii) inadequately skilled or trained academic staff to lead research projects and/or supervise postgraduate students; (iv) institutional histories; (v) varying levels of support from industry as well as regional and local communities surrounding universities; and (vi) varying impacts of the evolving social discourses and national policy priorities (Mekoa, 2018; Reddy, 2004). In addition, there is a high level of variation with regards to ownership and access of RI within the higher education sector. These factors highlight the marked differences in status, infrastructure and capacities between those universities that are considered "historically advantaged" or "resource-rich" that previously catered for the minority white population; and those that are considered "historically disadvantaged" or "under-resourced" universities that were created by the Apartheid government to produce and domesticate emerging black elites. The latter, however played a pivotal role in eroding the legitimacy of the unjust Apartheid social form (Mekoa, 2018; Reddy, 2004).

> *Due to the legacy of the Apartheid system, the higher education landscape in South Africa remains highly differentiated despite efforts to reform the higher education system* (Mekoa, 2018; Reddy, 2004).

At the time of the democratic transition, the higher education landscape was comprised of 21 public universities and 15 technikons (Reddy, 2004). Post-1994,

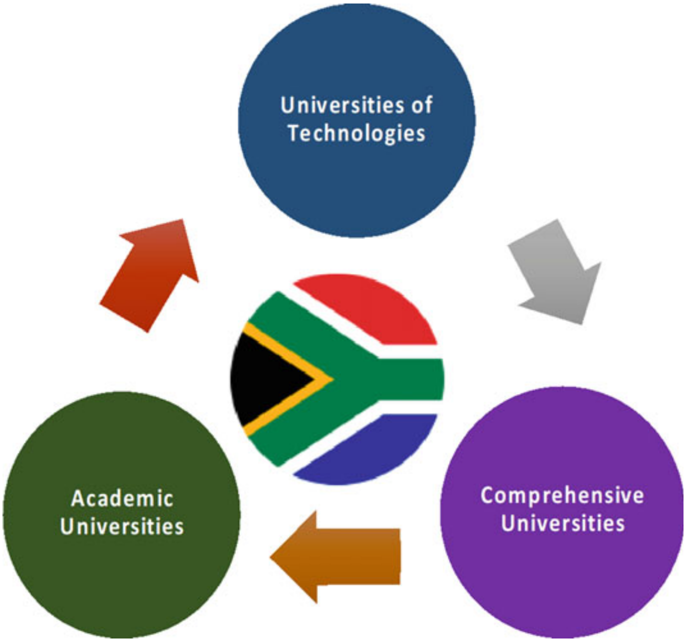


Fig. 1.6 Types of universities that comprise the South African higher education system

these higher education institutions were subjected to legal, administrative and policy changes which resulted in the morphing of the national higher education landscape. As of 2018, the university education system in South Africa comprises 26 public universities that can be classified as (i) 11 academic universities; (ii) nine comprehensive universities; and (iii) six universities of technology (South African Department of Higher Education and Training, 2016) (Fig. 1.6).

Universities of Technology: These universities have transformed from their original technikon status and offer more vocational-orientated or technical programmes or qualifications. The six institutions listed in alphabetical order below include:

- Central University of Technology
- Cape Peninsula University of Technology
- Durban University of Technology
- Mangosuthu University of Technology
- Vaal University of Technology
- Tshwane University of Technology.

Comprehensive Universities: These universities are a result of a merger between academic universities and technikons with the objective of enhancing institutional diversity at higher education institutions through the strengthening of synergies between career-focused and general academic programmes (South African Department of Education, 2004). These nine institutions are listed in alphabetical order below:

- Nelson Mandela University
- Sefako Makgatho University
- Sol Plaatjies University
- Walter Sisulu University
- University of Johannesburg
- University of Mpumalanga
- University of South Africa
- University of Venda
- University of Zululand.

Academic Universities: These universities offer more traditional theoretically-orientated academic-based training. The following eleven institutions are listed in alphabetical order below:

- North West University
- Rhodes University
- University of Cape Town
- University of the Free State
- University of Fort Hare
- University of KwaZulu Natal
- University of Limpopo
- University of Pretoria
- University of Stellenbosch
- University of Western Cape
- University of the Witwatersrand.

The 26 universities are spread across the country with the majority (eight) based in Gauteng, which is the smallest and most populous province in South Africa with approximately 14.7 million people (Statistics South Africa, 2018). The Western Cape and KwaZulu Natal come in second place by hosting four universities each. The Eastern Cape has three universities followed by Limpopo and the Free State which host two universities each. The least number of universities are in Northern Cape, Mpumalanga and the North West, each hosting one university. Figure 1.7 provides are illustrative map indicating the location of public universities in South Africa.

This classification system of the higher education landscape in South Africa is further entrenched by the performance indicators for this sector by government, which is largely based on research and/or research-related indicators. Public debate ensues with the objective of expanding the set of indicators. Muller (2013) suggests that the following indicators be utilised to assess performance at the higher education institution level:

- Undergraduate and postgraduate enrolment numbers.
- Number of academic staff by rank.
- Number of permanent academic staff with Ph.D.s.
- Number of research publications.
- Number of Ph.D. enrolments and graduates.

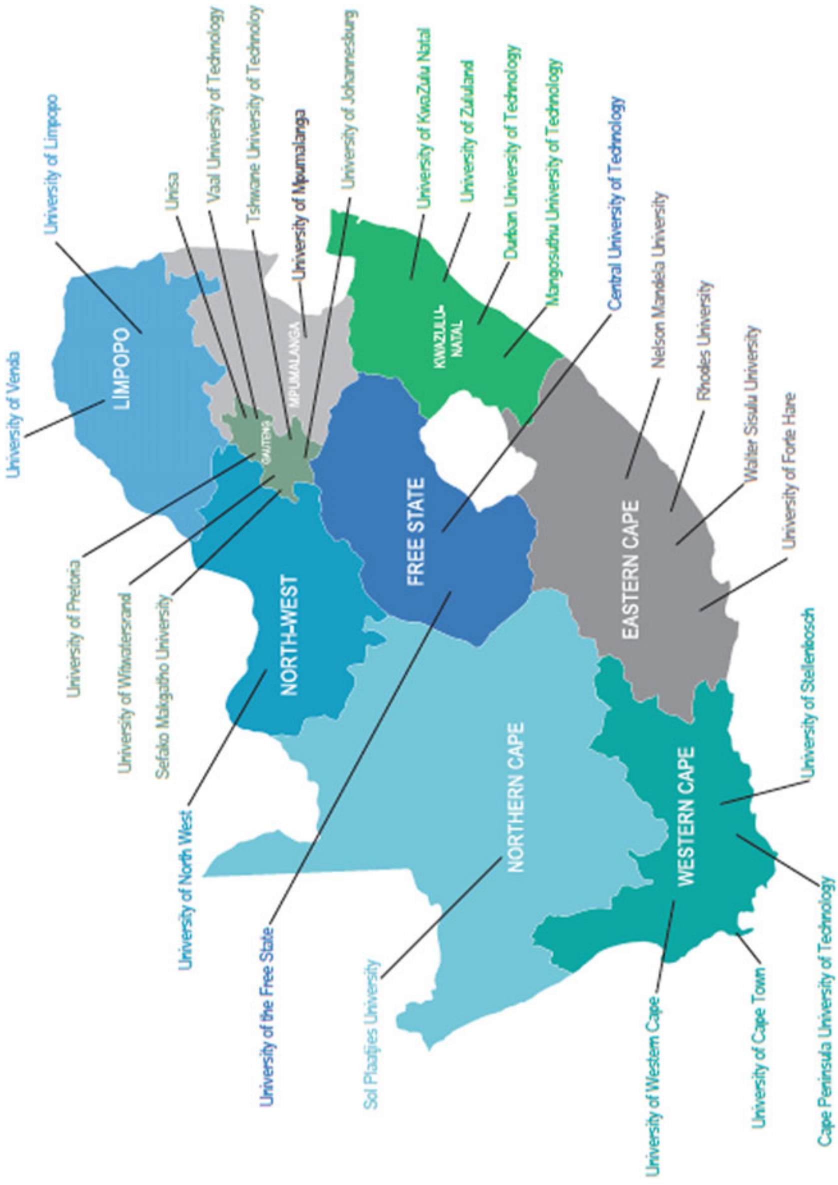


Fig. 1.7 The geographical spread of universities across the nine provinces in South Africa

To develop a holistic set of indicators will require a wider consultative process to be employed that focuses on identifying and understanding the needs and influencing factors impacting on the rather differentiated higher education sector in the country. Such factors include, amongst others, the strength of the institution's balance sheet and how this, in turn, contributes to the research institution's ability to deliver on the key performance indicators aligned to both knowledge generation and human capital development.

1.6 Overview of Research Infrastructure Investments in South Africa

Given the diverse and vital role that infrastructure plays in the research ecosystem as well as the associated high cost implications, the investment in infrastructure should be holistically planned and executed taking into account strategic leveraging and sharing of resources among key stakeholders at the national, regional and global levels.

In 2006, a study by Piperakis and Pouris highlighted the huge deficit of modern research equipment in South Africa. However, during the past decade, significant investments have been made through the NRF and its line department with the aim of improving the state of research equipment at research performing institutions in South Africa. As of February 2019, the NRF had awarded a total of 408 grants to 33 research institutions, comprising 23 universities and ten other research performing institutions, which includes non-degree awarding research performing institutions such as national research facilities and other public science councils, laboratories and museums, amongst others (National Research Foundation, 2018). The investment by the NRF is summarised in the Fig. 1.8.

Figure 1.9, indicates that the biggest recipient of NRF research equipment grants are those institutions based in Gauteng, which is not only home to the largest number of universities but is also considered to be the economic hub of the country, if not the continent.

It is not surprising, that academic universities have benefited significantly from the NRF equipment grants as seen in Fig. 1.10. This is largely attributable to their research intensive activities, which have held them in good stead when subjected to the scorecard linked to the NRF's equipment grants, which is discussed in detail in Chap. 3 (National Research Foundation, 2018).

1.7 Summary

This chapter provides a contextual background of the underlying policies and strategies that motivate the provision of RI which is deemed a critical enabler for the

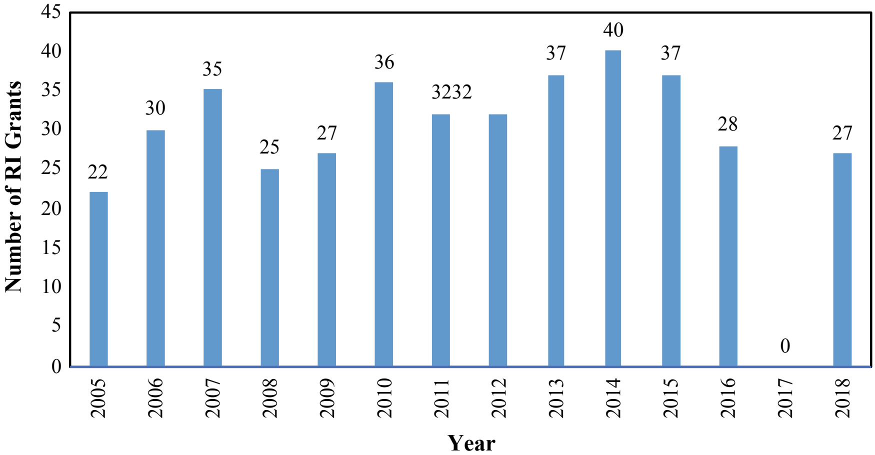


Fig. 1.8 Number of equipment grant awards per annum spanning the period from 2005 to 2018 (National Research Foundation, 2018)

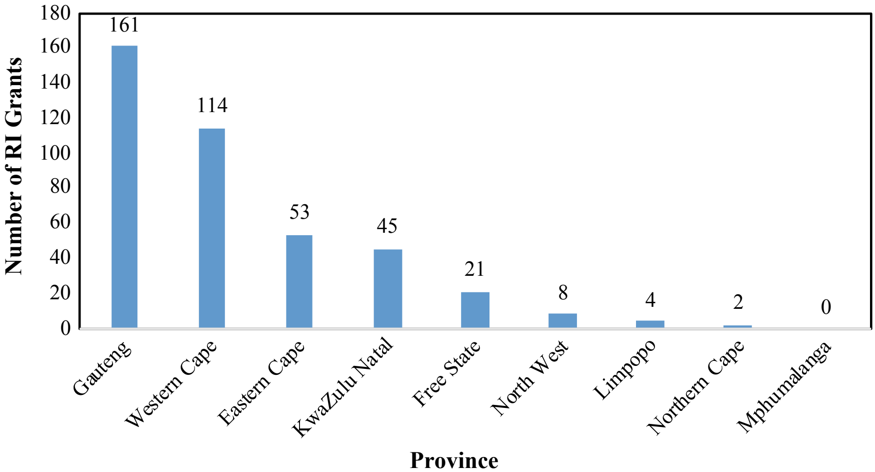


Fig. 1.9 Provincial distribution of equipment grants across the higher education landscape in South Africa (National Research Foundation, 2018)

realisation of the key national objectives and priorities. It also highlights some of the challenges that continue to face the higher education landscape in the country, and summarises the spread of investments made by the NRF in implementing the RI funding instruments over a 15 year time frame across this rather differentiated higher education sector.

This chapter sets the scene for further discussion on the approaches employed in the South African context to classify categories of infrastructure funding.

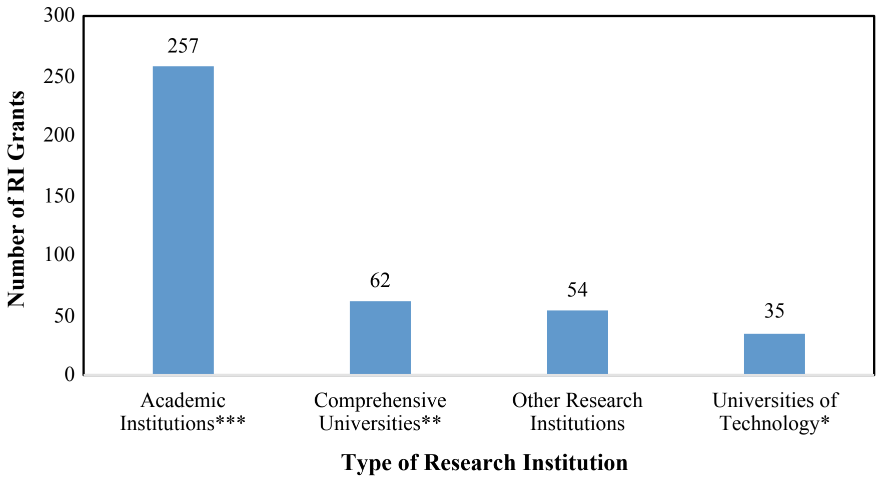


Fig. 1.10 Spread of equipment grants across the various types of research institutions in South Africa (National Research Foundation, 2018). *Only five of the six universities of technology received equipment grants. **Only seven of the nine comprehensive universities received equipment grants. ***All academic universities received grants

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Chapter 2
Classification of RI Investment Areas in South Africa

2.1 Approaches to Research Infrastructure Investment

The three approaches that are commonly used when assessing and identifying the need for investing and mainstreaming RI initiatives are the (i) bottom-up approach; (ii) top-down approach; and (iii) integrated approach (Khadka & Vacik, 2012). The bottom-up approach allows for innovative ideas to be supported by subject experts as well as numerous other key role players, without any boundaries or parameters. This approach facilitates the articulation of a specific need that may not necessarily be identified or displayed on the radar screen of government departments or funding agencies (Girdwood, 2013). The bottom-up approach promotes co-creation of research programmes through the direct involvement, participation and consultation of various stakeholders. Considering the stronger uptake and ownership factor, this approach is widely adopted in most developed countries (Girdwood, 2013), where researchers tend to have a strong voice when presenting a case for funding to funding agencies and government departments. Unfortunately, in developing countries, due to competing investment priorities and constrained budgets, there is a long lead time associated with the bottom up approach as funding agencies and government departments may not have the capacity to fund additional research activities, let alone funding for the provisioning of RIs.

The top-down approach entails the development and adoption of science and technology policies that are driven from the highest level of the state, which in turn is able to ring-fence a budget (Khadka & Vacik, 2012). Top-down policies demonstrate clear objectives and goals, hierarchy of authority, alignment to national imperatives, and resources to deliver on their implementation (Girdwood, 2013). However this approach may to some extent ignore the opinions and considerations of the research community. Consequently the implementation of many policies born from the top-down approach may be subject to scrutiny and failure (Girdwood, 2013).

R. Ramoutar-Prieschl and S. Hachigonta, *Management of Research Infrastructures: A South African Funding Perspective*,
https://doi.org/10.1007/978-3-030-37281-1_2

Fig. 2.1 Suite of high end microscopes available at the C-HRTEM at Nelson Mandela University, South Africa (Neethling, 2018)

Accelerated and impactful outcomes on RI investment require a dual approach to investments in RI, which integrates both the bottom-top and top-down approaches. This would, therefore, entail the development and adoption of science and technology policies on the one hand, driven from the highest level of the state and with dedicated ring-fenced budgets while on the other hand, the community is encouraged to participate and contribute towards policy formulation that addresses the requirements of the research community and societal needs (Girdwood, 2013). Such an approach tends to minimise the public demands for a short term return on investment from the usage of taxpayers' money and strengthens the impact of STI for societal benefit.

Case study *In 1983, the research community, driven by the Microscopy Society of South Africa, spearheaded an initiative for the establishment of a Centre for High Resolution Transmission Electron Microscopy (HRTEM) in the country. Due to the uniqueness of the equipment as well as the high costs related to procuring, housing, maintaining and operating the equipment, this proposal by the research community was deemed high risk by government departments, including funding agencies, at the time. Once a champion was identified to drive this initiative, the proposal was reformulated as a business plan with a strategy that defined mitigation steps for managing potential risks. In 2009, 26 years after the project was first conceptualised, the first tranche of investment was secured for the establishment of a National Centre for HRTEM, which was ultimately launched in 2011. The suite of microscopes are presented in* Fig. 2.1. *Since the launch of the Centre, spanning 2011–2018, the following highlights have been reported* (Neethling, 2018):

Outputs from 2011 to 2018:

- *Number of publications in accredited journals: 102*
- *Number of postgraduate students supported (Hons, M.Sc., Ph.D.): 253*

- *Number of collaborations established with African and international partners: 20*
- *Number of national collaborations established: 20*
- *Number of private sector partners: 6*

Research areas supported from 2011 to 2018:

- *Strong materials, energy security, biotechnology, nanotechnology, catalysis, power plant steels, and nuclear materials.*

2.2 Process for Acquiring RI

The process of motivating and securing a dedicated RI budget commences with a (i) needs assessment of RI; (ii) benchmarking of current RI against international developments; (iii) establishing and nurturing strong partnerships between stakeholders regionally, nationally and internationally; and (iv) clearly indicating the envisaged impact on the research landscape and society. The purpose of a needs assessment is to provide baseline information relating to the current state of (i) research infrastructure; and (ii) the human resources required to support such infrastructures. The process which is more complicated than it appears, can be guided by the following pertinent questions:

- What equipment is needed to support the national R&D agenda?
- What is the current state of research equipment across the national research landscape? Is the equipment functional, in storage, decommissioned, broken, other?
- What is the age of the equipment across the national research landscape?
- What are the investments to date in research equipment?
- What is the spread of research equipment in terms of its geographical placement or location within the country?
- How does the placement of equipment support and/or advance research niche areas that align to the geographical position of the country globally?
- What is the quantity of skilled human resources available in the country to support, operate and maintain the research equipment?
- What are the qualifications and experience of the human resources that are available to support, operate and maintain the research equipment?
- What is required to create a critical mass of skilled human resources that can support, operate and maintain the research equipment?
- What is the spread of the human resources in terms of demographics such as age, gender and race?
- How does the country fare against similar countries (benchmarking) in terms of research infrastructure and human resources.

- In which countries can collaborative networks be established for shared access to equipment and skills development?

This baseline and benchmarking groundwork sets the foundation for developing a framework for RI investments in a country, which in turn will feed into the development of a RI roadmap at a later stage. This framework can be further refined into a RI strategy which clearly defines RI investment categories, objectives, budgets and a timeframe within which specific deliverables or outcomes will be achieved.

The RI budget must support the development and/or acquisition of RIs that advance research in specific thematic areas that either explores and/or exploits the opportunities presented by the geographical positioning of the country globally. As an example, the geographical position of South Africa places it at a competitive advantage for research in areas such as (i) palaeontology; (ii) ocean currents; (iii) climate change; (iv) indigenous knowledge systems; (v) biodiversity; (vi) conservation; (vii) mining and minerals; and (viii) astronomy, amongst others (South African Department of Science and Technology, 2002).

Once the RI budget has been secured, a process must be developed that awards infrastructure grants on a competitive basis to public research performing institutions. The scientific case driving the justification or motivation for the infrastructure grant must advance the country's priority investment areas such as food security, clean water, energy security, health, poverty alleviation, amongst others. These areas in turn link to global programmes such as the SDGs and STISA 2024. Hence, a complementary, synergistic and integrated approach is required for mapping RIs, as outlined in Fig. 2.2.

2.3 Classification of RIS in South Africa

This section provides a model for mapping RI needs across the innovation value chain. Such a mapping exercise, was used to assess the RI needs across the innovation value chain in South Africa, comprising the integrated approach. This is described in detail in the draft research development and innovation funding framework that was launched by the Department of Science and Technology in 2010. Six major RI investment areas were identified and mapped against the four stages of the innovation value chain, i.e. (i) well-founded research laboratory equipment; (ii) scientific equipment; (iii) specialised facilities; (iv) high-end infrastructure; (v) access to global infrastructures; and (vi) cyber-infrastructure. A summary of the main RI categories is shown in Fig. 2.3.

Fig. 2.2 A complementary, synergistic and integrated approach is required for mapping RIs

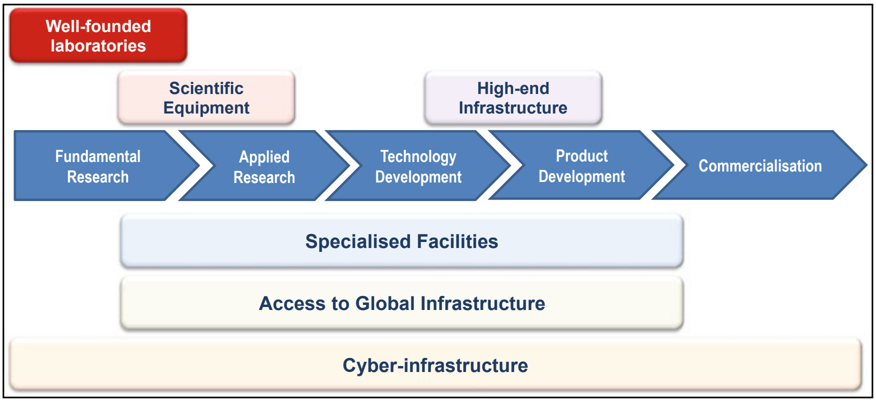

Fig. 2.3 Mapping the various RI funding categories across the innovation value chain

2.3.1 Well-Founded Laboratory Research Equipment

Well-founded laboratory research equipment includes the minimum level of equipment and facilities that need to be in place as a necessary requirement for conducting basic research and training postgraduate students. This sub-category of equipment refers to generally moveable or benchtop analytical or basic, entry-level instrumentation that is usually acquired and managed within a specific research group at a research institution. The full responsibility and costs associated with the equipment's operations, maintenance and access by other researchers or research groups is assumed by the research institution. Examples of this class of equipment include analytical NMR spectrometers; equipment for chromatography; and powder X-ray diffractometers. Well-founded laboratory equipment is usually a fundamental requirement for the functioning of any research and training laboratory, hence the funds required to support the procurement of such instruments must be sourced from either the research department or institution (South African Department of Science and Technology, 2010).

2.3.2 Scientific Equipment

Scientific equipment can be defined as those enabling research tools that are fundamental for conducting competitive research and training the next generation of researchers. Scientific equipment refers to dedicated, immovable, free standing, large, networked, multi-user and multi-disciplinary research equipment including all necessary ancillary components such as computers and specialised software, amongst others. In this case, resources need to be earmarked for constructing specialised buildings or other physical infrastructures for housing such equipment, in order to ensure that the optimal functional specifications of the equipment are met (South African Department of Science and Technology, 2010). Scientific equipment can be further divided into two sub-categories as follows:

- ***Large Scientific Equipment*** represents more specialised and dedicated equipment for multi-user and inter-disciplinary research programmes. This sub-category of equipment refers to those pieces of equipment that are fundamental to undertaking competitive research, training postgraduate students and developing staff, particularly in terms of technical and applications expertise. The acquisition, development and upgrade of specialised equipment by a particular institution also requires that the research institution assume responsibility for the service and maintenance costs associated with large scientific equipment. The institution is further responsible for ensuring that the equipment is accessible to users from other institutions, including industry, at a fee that is based on a cost recovery charge-out rate (South African Department of Science and Technology, 2010). Examples of this class of equipment transmission and scanning electron microscopes.
- ***Advanced Scientific Equipment*** constitutes the acquisition or development of unique, state-of-the-art multi-user, inter-disciplinary and highly specialised scientific equipment that is not only able to push the frontiers of science, but is also able to address the development of scarce skills, attract industrial involvement, drive scientific and technological productivity and advance national priorities. In

general, equipment in this sub-category is often too costly to be acquired by institutions individually and requires multi-institutional support. In the latter instance, institutions based within a specific geographical region tend to collaborate closely in order to either acquire or develop advanced scientific equipment that benefits the region itself. Depending on the scientific requirements, equipment of this nature may be placed in an independent location in a specific region in order to equally serve the needs of researchers within that region. In many instances this equipment will provide an international competitiveness to the development of a specific research area (South African Department of Science and Technology, 2010). An example extends to the suite of mass spectrometers available at the Institute of Wine Biotechnology at the University of Stellenbosch in the Western Cape. The institute focuses on understanding the biology of wine-associated organisms, including the ecology, physiology, molecular and cellular biology of grapevine, wine yeast and wine bacteria to promote the sustainable, environmentally friendly and cost-effective production of quality grapes and wine. The matrix-assisted laser desorption ionisation-time of flight mass spectrometry (MALDI-TOF MS) has aided the institute in the identification and diagnosis of microbes that contribute towards improving the quality of wine for both the local and global markets (Bauer, 2018).

Additional resources need to be earmarked to provide the necessary space, services, utilities, technical, operational maintenance, IT support, replacement and upgrade costs. In many cases, special attention to renovating physical infrastructures such as buildings may be required. An additional requirement motivating the investment in this sub-category of scientific equipment will be to establish a clear governance and/or management structure, and present a detailed business plan that clearly addresses the issue of sustainability.

The key criteria used for the provision of funding in the *Scientific Equipment* category may include:

- Equitable geographic distribution of equipment across the higher education sector including science councils in terms of access, areas of expertise and contribution to the national R&D agenda.
- Demographic distribution in terms of allocating grants in line with the redress and equity targets of the country.
- Sustainable management of equipment in terms of its placement and efficient usage and maintenance.
- Social impact in terms of benefits derived from the placement of the equipment or infrastructure to the people and communities (South African Department of Science and Technology, 2010).

2.3.3 Specialised Facilities

Specialised facilities (SF) are dedicated research performing institutions that houses large, unique and highly specialised physical RI that provides a controlled environment for ensuring the optimal performance of the research equipment as well as conducting highly specialised experiments. Examples of these types of research facilities include specially-constructed laboratories, biosafety containment laboratories, pre-clinical laboratories and research clean-rooms.

In the South African context, this category of RI includes the national research facilities (NFs). The NFs, managed by the NRF, play a critical role in the provision of unique and cutting-edge research infrastructure platforms in the country for the advancement of science and technology across the research enterprise. However, these facilities have been operating under financial duress, thereby constraining their ability to maintain and sustain the infrastructure platforms. This challenge has threatened the ability of the NFs to effectively deliver on their core mandates, i.e. accessibility, knowledge generation, human capital development, and science outreach and awareness.

> *National Facilities are centred on substantial instrumentation, equipment or skills base and is established to satisfy an identified national social, economic or technological need and which, because of expertise and capabilities, is justified on the basis of shared research and/or service used by external organisations. The facility is made available for research by internal and external researchers on the basis of the merit of proposals as assessed by peer-group review, while service work is commercially supplied to industry. The work programme of the facility is balanced to ensure an appropriate allocation of time to both research and service activities.* (South African Department of Arts, Culture, Science and Technology, 1996)

In summary, advanced specialised laboratories refer to infrastructure platforms that not only include the physical laboratory in a specific location, but also the suite of highly specialised scientific equipment. In most instances the equipment and geographic location are integrally linked to form a single infrastructure platform, i.e. the equipment and experiments cannot function optimally unless the environment subscribes to specific physical and environmental standards such as appropriate air-conditioning, reinforced flooring, noise and vibration cancellation systems, as well as controlled environments for humidity and temperature. Some examples of such laboratories include specialised microscopy facilities, such as the high resolution microscopy facilities; bio-repositories; radio-telescopes; research-focused forensic laboratories; research museums; research clean-rooms; biosafety, biohazard and radiation containment facilities; and oceanographic facilities.

The key elements linked to the provision of funding in this category include the:

- Physical infrastructure that is required to house the research equipment;
- Ancillary equipment or feeder equipment that will complement the capabilities of the research equipment;
- Research equipment;
- Funding towards the operational and maintenance costs as well as technical support that are required to ensure the sustainable management of the specialised laboratories.

The NFs, as outlined in Table 2.1 summarise South Africa's investment in this category of RI. Unfortunately these NFs have been operating under financial duress, which has consequently lead to constraining their ability to maintain and sustain the infrastructure platforms. This challenge has threatened the ability of the NFs to effectively deliver on their core mandates, i.e. accessibility, knowledge generation, human capital development, and science outreach and awareness. Some of the challenges include the inability to:

- Renew ageing equipment and infrastructure;
- Succeed and replace the aging workforce;
- Effectively manage ageing and obsolete equipment and infrastructure so as to minimise disruptions in operations;
- Acquire necessary state-of-the-art equipment to meet commitments and mandates; and
- Maintain and acquire additional infrastructure, including the upgrade of the existing infrastructure, to keep up with advancing technological developments (South African Department of Science and Technology, 2010).

In attempting to address some of the challenges reported above, the SARIR which was launched in 2016 attempts to prioritise the investment in the establishment of 13 specialised facilities across five thematic areas, as described in Table 1.1.

2.3.4 High-End Infrastructure

High-end infrastructure refers to the infrastructure needed to bridge the "innovation chasm" (refer to Sect. 1.2) with the objective of strengthening the commercialisation potential of products, processes and services. High-end infrastructure refers to specialised platforms or laboratories that support the transition from R&D to commercialisation. This type of infrastructure is required to demonstrate scalability and reproducibility in terms of processes, quantities and quality which are necessary prerequisites to full-scale manufacturing and commercialisation. It is also a crucial and necessary step to mitigate risk and secure venture capital (South African Department of Science and Technology, 2010). Examples of RI in this category include pilot plants, incubators, technology demonstrators and semi-commercial test facilities (Fig. 2.4).

Table 2.1 A summary of the NRF-managed national research facilities

National facility	Core business	Grand challenge that is addressed
The South African Radio Astronomy Observatory (SARAO)	SARAO supports research and training in radio astronomy and space geodesy. It includes the (i) Square Kilometre Array Radio Telescope, commonly known as the SKA; (ii) radio astronomy instruments and programmes such as the MeerKAT and KAT-7 telescopes in the Karoo; (iii) the Hartebeesthoek Radio Astronomy Observatory (HartRAO); and (iv) the African Very Long Baseline Interferometry (AVN) programme in nine African countries	Space Science and Technology
iThemba Laboratory for Accelerator Based Sciences (iThemba LABS)	Provides advanced, viable, multi-disciplinary facilities for training and services in the fields of sub-atomic nuclear sciences and applied radiation medicine	Farm to pharma (radiation therapy and isotope production) Energy security (High-energy nuclear physics)
South African Astronomical Observatory (SAAO)	Performs fundamental research in astronomy and astrophysics and supports the Southern Africa Large Telescope (SALT)	Space Science and Technology
South African Environmental Observation Network (SAEON)	An emerging facility that establishes and maintains nodes linked by an information management network. These nodes serve as research and education platforms for long-term studies of ecosystems and assist in the development of methods to detect, predict and react to environmental change	Global Change (long term in situ environmental monitoring, environmental information systems)
South African Institute for Aquatic Biodiversity (SAIAB)	Serves as a research hub for aquatic biodiversity in Southern Africa by housing and developing the National Fish Collection as well as other sources of aquatic biodiversity data	Global Change (long term observation of biodiversity in aquatic environment)

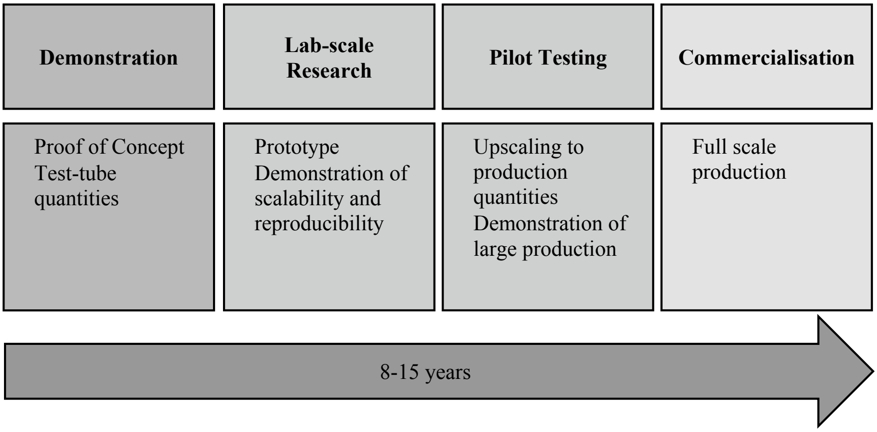

Fig. 2.4 Key components of product development within the innovation value chain (South African Department of Science and Technology, 2010)

The key objectives for building, operating and maintaining pilot plants are as follows:

- To reduce the technical and financial risks for scaling up the selected technology to full scale production;
- To reduce marketing risks by producing sufficient quantities of the product that can be tested by potential customers;
- To troubleshoot, align and resolve any challenges that may impact on the downstream processing technologies required for full scale production;
- To provide an experiential training facility for future employees of the envisaged full-scale plant; and
- To provide a facility for ongoing technology development such that there exists the possibility to expand the proposed range of products and/or services (South African Department of Science and Technology, 2010).

The key criteria for the provision of RI funding in this category may therefore include assessing the level of: (i) innovation; (ii) economic impact; (iii) industry partnerships; and (iv) beneficiation of raw materials.

2.3.5 Global Research Infrastructures

Global research infrastructures (GRIs) are recognised as critical enablers for advancing scientific knowledge, research outputs and innovations, as well as accelerating the training and development of the next generation researchers (Group of Senior Officials, 2017). Global research infrastructures can be classified as (i) '**single-sited**', i.e. a single resource at a single location, such as the Large Hadron Collider (LHC);

(ii) '**distributed**', i.e. being part of a network of distributed resources, such as ocean, earth or seafloor observatories; or (iii) '**virtual**', i.e. the service is provided remotely, such as simulation environments. Regardless of the type of global infrastructure, there is a fundamental need for the management of big data and high-speed networks for the optimal sharing of data and other resources (South African Department of Science and Technology, 2010).

The SKA project is an international effort to build the world's largest radio telescope, with eventually over a square kilometre (one million square metres) of collecting area. It is one of the largest scientific endeavours in history and brings together scientists, engineers and policy makers from around the world. The SKA core high and mid frequency telescopes are hosted in South Africa's Karoo region, ultimately extending over the African continent. Australia's Murchison Shire hosts the project's low-frequency antennas.

In this regard, GRI facilities are critical enablers for high quality teaching and training as well as conducting cutting edge research and driving innovation. This category of funding requires parallel investments in travel or mobility grants to facilitate access to RI facilities, including the **outbound access** to GRIs, which refers to national researchers travelling abroad, usually to the global north, to GRIs such as synchrotrons and the LHC at the *Conseil Européen pour la Recherche Nucléaire* (CERN), to name a few. The other type of access is **inbound access**, which refers to researchers accessing those GRIs that are located within a specific country. In the South African context, these include the national research facilities: Southern African Large Telescope (SALT) and Square Kilometre Array (SKA).

As seen by the examples presented above, the complexity and high development, construction and operational costs associated with GRIs make it rather difficult for a single country to build, maintain and operate. Consequently, efforts towards the internationalisation of large-scale GRI that have evolved to meet the scientific demands that extend further than the geographical boundaries of individual countries or institutions (Group of Senior Officials, 2017). It requires a multi-pronged and multi-user approach in terms of leadership, scope, cost and complexity. Global research infrastructures have been identified as research platforms that do not only provide essential RI platforms for the generation of internationally competitive science and technology outputs but also represent global collaborative geared towards addressing key sustainable development challenges that are articulated in the SDGs and STISA. These GRIs are influential in attracting the best researchers from around the world and building bridges between national and international research communities and scientific disciplines to address research issues that cannot be tackled by a single institution, region or country services (South African Department of Science and Technology, 2010).

The potential for increased cooperation on GRIs has long been recognised at high-level science diplomacy meetings. A Group of Senior Officials (GSO) on GRI was established at the first Group of Eight (G8)[1] Science Ministers' Meeting in 2008 (European Commission, 2018) and has been active since 2011. The primary objectives of the GSO are to: (i) identify RI of global interest, (ii) analyse how countries evaluate and prioritise the construction of large scale RIs, (iii) identify possible new areas of cooperation, (iv) promote transnational access to GRIs, (v) foster "distributed" RIs, (vii) identify measures to ensure that scientific data is appropriately handled, stored and accessed, and (vi) adopt a common understanding for the joint lifecycle management of GRIs (European Commission, 2018).

The GSO advocates for global excellence-driven access to the GRI. The recommendation by the GSO to GRIs is to employ peer review processes that approves access based on scientific excellence of the most promising emergent ideas, regardless of the country's membership status with the GRI (Group of Senior Officials, 2017).

Membership tends to be defined in medium to long term contractual arrangements between GRIs and countries. When a country enters into a fixed-term (or indefinite) membership agreement with a GRI, dedicated funding is required by that country for membership fees that facilitate the access of researchers in that country, to the GRI. Funding directed towards supporting this venture requires due consideration to the following costs:

- Membership fees, including contributions towards the maintenance and upgrade of the infrastructures at the GRI;
- Mobility and other related travel;
- Accommodation; and
- Charge-out fees.

The processes employed by GRIs to allocate access time to utilise their infrastructure facilities to both member and non-member countries is essentially based on a merit system, underpinned by scientific excellence (Group of Senior Officials, 2017). In general, the following process is adopted by GRIs:

[1]GSO is composed of representatives from Australia, Brazil, Canada, China, the European Commission, France, Germany, India, Italy, Japan, Mexico, Russia, South Africa, United Kingdom and United States of America (European Commission, 2018).

- Calls for proposals are opened by the GRI;
- Researchers across the globe apply through the GRI application process to utilise the facilities/laboratories/beamlines;
- Discipline specific peer review processes are undertaken by the GRI. All applications are reviewed against excellence; and
- Outcomes of the review process are communicated to all applicants by the GRI. Successful applicants are provided with the contact details of the manager of each facility/laboratory/beamlines, to proceed to book access time.

A common approach used by most GRIs is to allocate a set portion, of the total available access time to usage by the researchers from countries that do not hold membership, but have demonstrated excellence in their applications.

Some of the key international GRI facilities that are currently accessed by South African scientists, through formal collaborative agreements, is summarised in Table 2.2. The underpinning objectives linked to the access to GRIs include:

- To grow the expertise pool, in terms of (i) postgraduate students; (ii) emerging researchers; and (iii) staff development, with respect to building their research

Table 2.2 Summary of current and proposed SA memberships to GRIs (National Research Foundation, 2018)

Name of GRI	Objectives
Joint Institute for Nuclear Research (JINR)	The main objectives for South Africa's membership to JINR is to provide the South African research community with access to world-class facilities, research and networking opportunities in nuclear sciences with the JINR scientific community in Dubna, Russia
European Synchrotron Radiation Facility (ESRF)	The main objectives for South Africa's membership to ESRF is to provide the South African research community with access to world-class synchrotron facilities, including the various beamlines as well as research and networking opportunities across a multitude of research disciplines
European Organisation for Nuclear Research (CERN)	The SA-CERN programme gives South African researchers and postgraduate students access to the largest open research facility in the world, which is based in Switzerland. South African researchers and postgraduate students participate in a SA-CERN Theory Group and in three experiments in the Large Hadron Collider (LHC) at CERN, viz • ATLAS (a Torodial LHC Apparatus); • ALICE (a Large Ion Collider Experiment); and • ISOLDE (Isotope Separator on Line Device)

capacity and increasing knowledge outputs in specialised research areas that align to the geographical positioning of the country;
- To stimulate the development of technical expertise and technology transfer through both outbound and inbound collaborations;
- To build a strong local infrastructure base that complements the capabilities of the instrumentation available at GRIs. This allows for optimal and effective usage of the instrumentation at GRIs by national researchers; and
- To foster and nurture international partnerships that advance the science trajectory of the country.

Besides the facilitation of joint research, innovation and knowledge sharing, GRIs play a key in the training of students and researchers. The teaching and training programmes for researchers and students at the local infrastructure facility may include joint hosting of (i) winter or summer schools; (ii) specialist schools; and (iii) reciprocal collaborative support programmes that encourage researchers and students based at international GRI facilities to visit the local infrastructure base. These interventions are necessary to enable the scientists and students to derive maximum benefit from participation in the projects undertaken at global infrastructure facilities. It also strengthens synergies of scientific endeavours on the continent which, at a later stage, can be leveraged to consider the establishment of a singular African memberships to GRIs that are hosted in the global north. The partnering of countries on the continent will also lead to a more sustainable and cost effective mechanism for accessing essential GRI platforms.

Over and above the formal agreements with GRIs, a country should have in place a general equipment-related travel and training grant that makes funds available to support the larger science community with the objective of affording access to (i) other internationally based state-of-the-art equipment that does not form part of any formal agreements; and (ii) nationally-based research equipment that is not available at the home research institution or region.

2.3.6 Cyber-Infrastructure

Cyber-infrastructure refers to information and communication technology (ICT)-based infrastructures such as (i) high performance computing; (ii) broadband research networks; (iii) data storage and management systems; and (iv) grid and cloud computing infrastructures. These platforms contribute to the comprehensive infrastructure that is needed to address the complex, multi-disciplinary and cross-border needs of modern science. The evolution of science and technology has relied heavily on the exploitation of advances in ICT and the integration of hardware for computing, data management and manipulation as well as experimental facilities that require an inter-operable suite of software and middleware services and tools (South African Department of Science and Technology, 2010).

Investments in cyber-infrastructure is driven by the ever increasing need for analysis and storage of **large data sets from many sources**, including data captured by research equipment, data generation by simulations and sensor networks. Examples of disciplines that are mostly affected by such large data-sets include genomics and astronomy. These demands have given rise to **e-science**, which can be defined as the set of tools and technologies that support data federation and collaboration for the purposes of data analysis and mining, data visualisation and exploration, and communication. As a consequence, there are growing investments in **e-infrastructure** which refers to a combination and interworking of (i) digitally-based technology (hardware and software); (ii) resources such as data, services and digital libraries; (iii) communication, which includes protocols, access rights and networks; and (iv) people needed to support modern, internationally leading collaborative research across the sciences (Hey, Tansley, & Tolle, 2009).

The investments in this category of funding links to (i) high bandwidth networks; (ii) infrastructure; (iii) open-source; (iv) technologies and standards for data provenance, curation and preservation; (v) super-computing; and (vi) training of scientific software engineers and data scientists (Hey et al., 2009).

> *Cyberinfrastructure consists of computing systems, data storage systems, advanced instruments and data repositories, visualisation environments, and people, all linked together by software and high performance networks to improve research productivity and enable breakthroughs not possible otherwise*. (Steward, Simms and Plale, 2010)

Cyber-infrastructure plays a critical role in the knowledge-triangle (Fig. 1.1) as well as the innovation value chain. Cyber-infrastructure underpins the various categories of research infrastructure as proposed in this book, which include (i) scientific equipment; (ii) specialised facilities; (iii) high-end infrastructure; and (iv) GRIs. This type of infrastructure essentially requires computing, data storage and management, transmission and/or communication networks and application development services. Cyber-infrastructure is a pre-requisite in addressing pertinent issues such as the need to store, analyse and process unprecedented amounts of heterogeneous data and information that form the enabling backbone that supports the establishment of world-class scientific collaborations as well as accessing and sharing scientific resources and information regardless of the source or nature of such information or its location. Closely linked to enhanced computational power and networks as well as data storage and management is the need for applications and competence development that focuses on the establishment, optimal use and sustainability of cyber-infrastructure in South Africa (South African Department of Science and Technology, 2010).

The South African Information and Communication Technology Research Development and Innovation (ICT-RDI) Roadmap was launched in 2015. This roadmap provides strategic national direction, a set of action-plans and an implementation framework to guide, plan, co-ordinate and manage South Africa's investment in the sector (South African Department of Science and Technology, 2015). This framework highlights six clusters of opportunity, such as:

- Broadband services and infrastructure, which relates to both future wireless technologies and broadband service infrastructure. While wireless technologies relate to the design and development of technologies that respond to changes in the market-demand for wireless broadband services, broadband service infrastructure focuses on the utilisation of public broadcast and wireless spectrums with the intention to increase access via more available and less costly broadband.
- ICT for development refers to the application of ICT that contributes towards socio-economic impact. This includes (i) enhancing agricultural production; and (ii) the promoting e-inclusion for the removal of barriers to the use of ICT technologies by disadvantaged individuals and communities.
- Sustainability and the environment refers to using ICT to (i) support a greener environment; (ii) sense, observe and model global changes relating to climate, human migration, and environmental factors to name a few; and (iii) geo-spatial applications relating to observations from space and in situ environmental and disaster management.
- Industry applications makes reference to smart infrastructures, mining, manufacturing, future internet applications, content creation and delivery, supply chain optimisaation and asset management.
- Grand sciences, includes (i) the big science initiatives in the country, such as the SKA initiative, to aid in data gathering, filtering, storage and mining techniques; and (ii) the application of ICT to bio-medical sciences especially in the area where biology meets medicine.
- Service economy includes the usage of ICT in mobile health, e-services, education, business model innovation and payment solutions (South African Department of Science and Technology, 2015).

These six clusters are influenced by big data, which is structurally diverse, complex and dynamic in nature (refer to Sect. 7.5), thereby posing a problem in many areas of science including innovation, technology, engineering, social sciences, arts and humanities (Fig. 2.5). The main components of the current South African cyber-infrastructure framework involves the National Integrated Cyber-infrastructure System (NICIS), which includes the Centre for High Performance Computing (CHPC), South African National Research Network (SANReN), the Data Intensive Research Initiative of South Africa (DIRISA) as well as the South Africa GRID Computing (SA-GRID) and the Cloud Initiative, which is still in the conceptual phase.

Fig. 2.5 Summary of the South African ICT-RDI Roadmap (South African Department of Science and Technology, 2015)

2.4 Summary

It is evident that the successful implementation of STI strategies and policies is heavily reliant on the provision of a strong RI base, a skilled workforce, financial resources and collaborative networks. Research infrastructure can stimulate innovative research across the innovation value chain, critical for the realisation of a vibrant national system of innovation. The classification system presented here highlights the important role of research infrastructure in the advancement of (i) science, technology and innovation efforts; and (ii) skills development in the country.

In order to inspire the research enterprise to develop world class leaders, it is necessary to invest in RI, scientific equipment and specialised laboratories to ensure that the objectives set forth by the national policies are addressed at the upstream end of the innovation value chain. For instance, in order to bridge the gap between knowledge generation and the realisation of the commercial potential associated with the application of that knowledge, it is important to invest in high-end infrastructure. Furthermore, cyber-infrastructure forms the foundation for various RI which essentially require computing, data storage and management, transmission and/or communication networks and application development services. Cyber-infrastructure is a prerequisite in addressing issues such as the need to store, analyse and process unprecedented amounts of heterogeneous data and information. It forms the enabling backbone towards accessing and sharing scientific resources and information regardless of the nature of such information and its location.

Finally, the support of 'Fundamental or Basic Science' questions is an area of priority investment for any country. Hence it is important to provide mechanisms that facilitate mobility and access to these global infrastructures, necessary for the development and advancement of research capacity and human capital in the quest to seek answers to questions that relate to understanding the building blocks of life or global challenges such as climate change, biodiversity, energy security, health, food and water security.

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Chapter 3
Process for Awarding RI Grants

The RI grant life cycle comprises four major phases that are described below and summarised in Fig. 3.1. The first phase is the pre-grant award phase, which involves (i) soliciting research applications or proposals from the research community; (ii) assessing and reviewing applications; (iii) making funding decisions; and (iv) preparing grant award letters. The second phase includes the grant award phase, which entails approving the (i) funding decisions; (ii) communicating outcomes to all applicants; and (iii) preparing the legal document for the funding agency to contract with the grant holder by specifying the terms and conditions relating to the awarding of the grant which is presented in the document termed Conditions of Grant Award. The third phase is the post-grant award phase which is triggered by the staff within the funding agency issuing the Condition of Grant Award to the grant holder. Thereafter numerous monitoring and evaluating activities commence that include (i) financial expenditures; (ii) adherence to the management plan that was submitted by the grant holder as part of the original application; and (iii) reporting on the key performance indicators (KPIs). The fourth and final phase is the project close-out phase, which requires the grant holder to submit a final report on the financials, programme, grants-related activities, successes and challenges. At this stage representatives from the funding agency may need to conduct a site visit or technical audit to ensure that the grant holder has complied with all the conditions related to the grant award (Kwak & Keleher, 2015).

3.1 Pre-grant Award Phase

Competitive processes are employed to solicit applications or proposals for RI grants. When a call for applications is announced, a deadline is also specified by the funding agency for eligible applicants from eligible research institutions to prepare their applications against the pre-defined requirements. Completed applications with the necessary endorsements in the form of signatures of both the applicant and the

R. Ramoutar-Prieschl and S. Hachigonta, *Management of Research Infrastructures: A South African Funding Perspective*,
https://doi.org/10.1007/978-3-030-37281-1_3

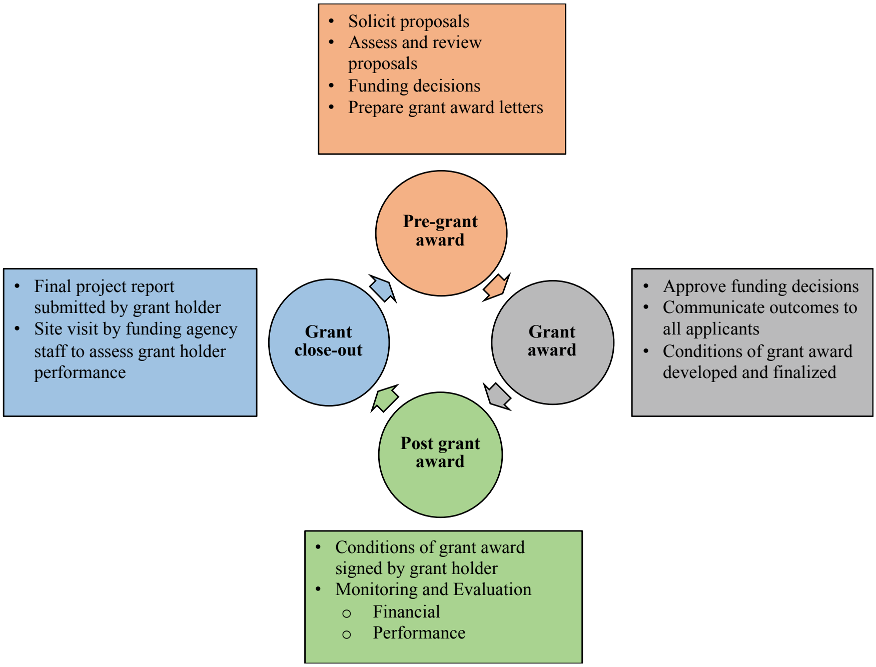

Fig. 3.1 Grant lifecycle (adapted from: Kwak and Keleher, 2015)

research institution's research management representative or designated authority are submitted within the specified timeframe to the specified funding agency contact person.

A pre-screening process follows, where the funding agency (i) logs the applications received and provide a summary of each application; and (ii) conducts an assessment to ensure that all applications meet the minimum eligibility criteria for both the applicant and the research institution. If the eligibility criteria is not met, the application does not proceed to the next phase of evaluation. In instances where there may be minor administrative gaps in the application, the funding agency may provide applicants with the opportunity to revise their applications within a stipulated time frame so that the eligibility criteria are met. In such instances, once all eligibility criteria have been revised and met, the application proceeds to the next phase of evaluation (Table 3.1).

3.2 Peer Review

A common approach for conducting peer review processes is by either (i) panel review; (ii) mail review; or (iii) both. Both review processes are based on insights and

Table 3.1 Example of a pre-screening spreadsheet

Criterion	Details
Name and surname	Prof XYZ
Citizenship or identity or passport number	SA1234567
Research institution	University of Research
Department or discipline	Structural biology
Name of equipment applied for	300 kV field emission gun transmission electron microscope
Type of equipment	Microscope
Preferred supplier	Microscope Africa (Pty) Ltd
Cost of equipment (incl. 3 year maintenance plan)	ZAR 10,000,000
Institutional contribution towards the cost of the equipment	ZAR 3,333,333
Amount of funds requested from funding agency	ZAR 6,666,666
Comments	Met all pre-screening requirements

recommendation of well-informed experts on various quality dimensions of research, as guided by a scorecard (Ruegg & Feller, 2003). The following section provides a detailed discussion and comparison of the panel and mail review processes.

3.2.1 Panel Review

In a panel meeting, reviewers are co-opted by the funding agency and a formal meeting is convened. There is usually an appointed chairperson who ensures that all applications, as logged and pre-screened by the funding agency, are reviewed with clear recommendations provided by the panel. The role of the chairperson is to facilitate the discussion on an application and guide the panel towards a consensus decision to either “fund” or “not fund” a specific application. The chairperson will also ensure that an appropriate length of time is allowed for the evaluation of each proposal. In addition to having an appointed chairperson, there is also an appointed assessor who ensures that personal biases from any appointed reviewer is minimised. The assessor’s role is also to ensure that the processes adopted during the meeting are fair and transparent and that the same criteria are applied consistently by all the panel members for the evaluation and scoring of all applications. In essence, the role of the assessor is to ensure procedural consistencies are applied when evaluating proposals. At the end of the panel meeting, both the chairperson and the assessor will submit a jointly written report which will be used by the funding agency to either improve or retain specific review processes. Supporting the chairperson and assessor in a panel meeting is a rapporteur whose role is to capture the proceedings of the meeting on a verbatim basis. This is an important process as it ensures transparency as well as provides a reference point for contestations that may arise from time to time, especially if researchers were unsuccessful in their application to obtain funding and require detailed feedback.

The role of reviewers is to make recommendations to the funding agency on whether each application, when considered in their entirety, should be funded or not. The panel is required to use the prescribed scorecard from the funding agency as a guide for evaluating the applications. The panel reviewers are required to submit a completed reviewer evaluation form at the end of the meeting that can also be used by funding agency staff to provide feed back to the applicant. This report must outline the successes, challenges and areas for improvement in the submitted application. During the panel review, usually two reviewers present a research proposal to the rest of the participants of the peer review group (Braun, 1998). This opens the floor to dialogue and opposing views by the other panel participants. There is a tendency in this review method for those reviewers evaluating a proposal to have the prerogative in the decision on whether or not a project is successful (Lee & Harley, 1998). Although a peer review can gain consensus on proposals that are either outstanding or poor, it is difficult to reach a consensus on proposals that score in the middle range which is a major limitation associated with the peer review system (Kostoff, 1994). At this stage, the role of both the assessor and chairperson becomes of paramount importance, especially in terms of ensuring that the key purpose of a peer review is to support outstanding proposals and reject those proposals that are deemed poor.

The drawbacks associated with the panel review method are cost implications and an inherently subjective decision making process that depends on the interests, experience and knowledge of the evaluators (Lee & Harley, 1998). Furthermore, the quality of the review can never go beyond the competence of the reviewers (Kostoff, 1994). It is, therefore, essential that the reviewer profile of the panel includes a combination from different countries and research backgrounds that span the spectrum of disciplines shortlisted in the pre-screening process, e.g. physical sciences and biological sciences. The use of international reviewers that host and manage mega-RIs should be identified as potential reviewers. These reviewers not only provide an independent and objective expert perspective but also guide the funding agency on best practices, risks, opportunities and challenges relating to the investment in RIs. A drawback to the use of international reviewers is their lack of understanding of local or national imperatives and context.

3.2.2 Mail Review

Funding agencies also employ a mail or postal review system where referees or reviewers decide on the credibility of the proposal and the research applicant in accordance with the guidelines and a scorecard prescribed by the funding agency. In the mail review system, the referee or reviewer makes an independent decision without being exposed to the opinion(s) of other reviewers (Lee & Harley, 1998). Usually two or three mail reviewers are requested on the same project proposal in order to balance the views of proposals. One of two processes can unfold post the submission of mail review reports.

Firstly, the reports can be anonymised and subsequently fed as source documents into the panel review meeting. These mail review reports provide an alternate perspective on the proposals to be evaluated at a panel meeting. If this process is undertaken, the panel reviewers have the final decision relating to whether or not a project is successful. Secondly, the reports are used by the funding agency staff to make the final decision on the outcomes of the application (Braun, 1998).

The general experience in the South African context is that the poor quality of the postal review reports do not provide adequate information for a decision to be made by either the funding agency or panel reviewers on whether or not an application should be funded. Hence the consensus is that the panel review be exclusively employed which aids in reducing (i) the complexity related to awarding RI grants; and (ii) the conflict(s) of interest that may emerge due to the small pool of reviewers available in the country.

3.3 Developing a Suitable Scorecard

All reviewers, both panel and postal, evaluate the merit of RI grant applications against the various funding agency-defined evaluation dimensions as presented in a scorecard. The awarding of research equipment grants should be based on a robust scorecard that, in turn, is informed by the national research strategies, scientific excellence and potential research impact. For example, reviewers for the United States National Science Foundation (NSF) use a four-criterion process to assess proposals, viz. (i) researcher performance competence; (ii) intrinsic merit of the proposed research; (iii) utility or relevance of the research; and (iv) the effect of research on the infrastructure of science and engineering (Kostoff, 1994). In the case of the Public Health Services projects, the criteria for the reviewers include (i) significance and originality of the proposal from a scientific and technical point of view; (ii) adequacy of the methodology to carry out research; (iii) qualification and experience of the principle investigator and staff; (iv) availability of resources; (v) justification for the proposed budget; (vi) duration of the projects; and (vii) other discipline-specific regulatory approvals such as ethics approvals when the project involves human or animal subjects and biohazards (Kostoff, 1994). Similar scorecards are utilised by other funding agencies across the globe.

Table 3.2 Example of a RI scorecard and the associated evaluation dimensions (National Research Foundation, 2018b)

Criterion	Descriptor
Management plan	Completeness, feasibility and efficiency of the proposed equipment management plan
Scientific merit	• Scientific merit of the proposed research • Research track record of the applicant and co-applicant
Human capital development (HCD)	• HCD track record of applicant and co-applicant • Current HCD activities of applicant and co-applicant (demographic profiles to be also considered) • Proposed HCD activities
Collaboration	Evidence of current and proposed collaborations: • Intra-institutional collaborations • Regional and national collaborations • International collaborations • Private sector and industry collaborations

In essence, the scientific case must drive and underpin the justification for any research equipment.

For example, the RI scorecard used by the NRF as a guide for reviewers could include the following essential criteria:

- Feasibility of the proposed management plan (see Management Plan section);
- Scientific merit of the proposed research to be undertaken if the equipment is procured;
- Researcher's track record in terms of (i) scientific publications using similar equipment; and (ii) human capital development (HCD) including training post-graduate students, postdoctoral fellows and young and/or emerging researchers; and
- Proposed research collaborations which will be the indicator of how access to the equipment will be promoted to other researchers. This proposed plan for research collaborations needs to be calibrated by the track record of the applying researcher in terms of historic collaborations that they have undertaken, nurtured and sustained (National Research Foundation, 2018b) (Table 3.2).

3.4 Grant Award Phase

This phase of the grant life cycle involves (i) finalising and approving the funding decisions; (ii) communicating the outcomes of the review process to all applicants; and (iii) receiving the signed conditions of grant award from successful applicants that are thereafter referred to as grant holders (Kwak & Keleher, 2015).

3.4.1 Funding Decisions

Post the evaluation process, funding decisions need to be approved by senior management within the funding agency which summarises the list of applications or proposals that were submitted post the closing of a call. It also specifies all those applications that were:

- Submitted during a call and were either:
  - Rejected at the pre-screening stage due to their not meeting the eligibility criteria; or
  - Approved for further review at the pre-screening stage
- Submitted for peer review and were either:
  - Recommended for funding; or
  - Not recommended for funding

In some instances, an additional category may be included in the funding decision spreadsheet, e.g. in instances where budgetary constraints prevent funding agencies from fully supporting the list of applications that are recommended for funding by the peer review committee. This, therefore, warrants the inclusion of a separate category, usually entitled: "Recommended for funding, but not awarded due to budgetary constraints. These applications must be awarded if additional funds are made available by the funding agency". This category then becomes a priority list for approval of funding should additional funds become available in support of RI grants (National Research Foundation, 2018b). A summary of the processes involved in grants management is presented in Fig. 3.2.

Once the funding decision spreadsheet has been approved, the funding agency communicates review outcomes to all applicants. A grant award is sent to successful applicants who have to comply with the requirements set forth in the Conditions of Grant Award which is a governance and risk management tool (National Research Foundation, 2018b). Communication is also sent to applicants that were not successful in soliciting grant funds, with detailed feedback on the gaps and the areas in the application that require strengthening.

3.5 Post Grant Award Phase

This phase refers to the monitoring and evaluation activities employed by the funding agency in an oversight capacity to assess financial expenditures, adherence to the work plan and reporting on key performance indicators (KPIs) as prescribed in the Conditions of Grant Award (Kwak & Keleher, 2015). The funding agency plays a proactive role in tracking performance and identifying red flags against the following indicators:

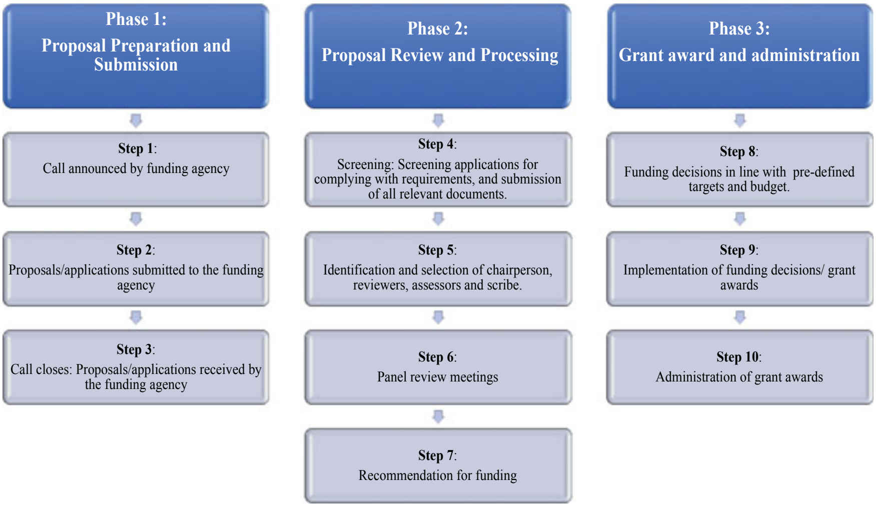

Fig. 3.2 Summary of the review processes utilised to evaluate applications for RI funding (National Research Foundation, 2018b)

- **Programme-related indicators** which include performance against management plan deliverables in line with the KPIs set forth by the funding agency. This includes, but is not limited to, drop-out rates of students, timelines for achieving pre-defined activities, amongst others (Kwak & Keleher, 2015).
- **Management-related indicators** which relate to any special conditions against which grants were award. This includes the development of an institutional plan for risk management which includes, but is not limited to, change of grant holder, loss of technical staff (either through retirement, resignation or death), challenges with supplier support, and other support capabilities including building infrastructure, required for the functionality of the research equipment (Kwak & Keleher, 2015).
- **Financial indicators** which refers to the drawing down of the grant in a timely manner as defined in the management plan (Kwak & Keleher, 2015). These will be described in detail under Monitoring and Evaluation.

In the event of red flags materialising, the funding agency must comply with a consequence management framework that puts in place measures such as (i) a recall of the grant investment from the funding agency; and (ii) prohibiting the research institution for a minimum period of three years from applying for additional research equipment grants or until such time that the institution fully addresses the red flag(s).

3.6 Project Close Out Phase

This is the final phase of the grant life cycle which requires the funding agency to (i) undertake a site visit to the research facility of the grant holder; and (ii) receive a project close-out report that summarises the financials, programme and grants-related activities, successes and challenges related to the RI grant (Kwak & Keleher, 2015).

3.7 Summary

Given the complexity, a limited number of reviewers, and a lack of experience and/or expertise of the reviewers or researchers on the use and management of equipment that are available within a country, the panel review process is recommended in the review of RI grants. The continued use of a panel review is further motivated by the fact that the international reviewers are able to (i) train national reviewers on how the peer review process is managed within their respective countries; and (ii) gain exposure to the researchers in the developing country, which can aid in the establishment of collaborations, mentorship programmes and staff and/or student exchange or sabbatical programmes at a later stage. Compared to panel reviews, selected cases in South Africa have shown that the quality of reports submitted by remote reviewers are below par. Caution and additional measures should be taken into account when considering this approach.

Finally, in order to improve and increase the number of exceptional reviewers, it is recommended that the funding agencies facilitate training courses on: (i) the objectives of RI funding instruments, (ii) the national contextual perspective and (iii) imperatives for new reviewers; and build strategic partnerships with experts and institutions across the continent and abroad.

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Chapter 4
Conditions of Grant Award

The usage of research contracts in the form of the Conditions of Grant, forms part of the risk management processes utilised by funding agencies in minimising their risks associated with their investment in RI grants. This contract must be signed by the grant recipient and the designated authority at the employing institution within a stipulated timeframe. The provisions of such a Conditions of Grant is presented in detail in this Chapter.

4.1 Usage of Funds

This section specifies and defines the terms and conditions linked to the awarding of a RI grant, including how grant funds may be utilised and reported. The Conditions of Grant affirms the approved management plan and budget that was submitted as part of the original research proposal that was subjected to peer review. Furthermore, the general consensus is that funds must be solely used for the procurement, upgrade and/or development of research equipment as stipulated by the funding agency in the award letter (National Research Foundation, 2018).

4.2 Institutional Responsibility

Institutional responsibility relates to the accountability that the research institution consents to, as part of the provisions of the conditions of grant. Some of these responsibilities and accountabilities that extend to research institutions include, but are not limited to:

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https://doi.org/10.1007/978-3-030-37281-1_4

- The equipment must form part of the research institution's asset register and be managed in accordance with its asset management policy;
- The institution must assume full accountability and responsibility for the record-keeping relating to the usage of the grant. Any information presented to the funder must be (i) accurate; (ii) complete; (iii) valid; (iv) reliable; and (v) transparent in line with good audit practice;
- The institution must co-invest to a value of one third of the purchase price of the equipment which must include a three-year maintenance contract with the supplier;
- The institution must undertake to (i) complete all necessary building renovations and/or construction against supplier or manufacturer specifications to house the research equipment; and (ii) ensure all security, services, utilities and insurance arrangements are in place;
- The institution must employ as well as retain the appropriately skilled staff to maintain and operate the research equipment and;
- The institution must have an access policy in place that ensures the research equipment is accessible and utilised by the wider research community, including students.

4.3 Ethics

All funded researchers must adhere to the highest ethical and safety standards when conducting research, particularly when human and animal subjects are involved. This requires compliance with all relevant regulations in this respect, including, but not limited to, those laid down by the research institution, national and international laws. A copy of the ethics approval for the research project, which will be undertaken using the awarded equipment, must be submitted to the funding agency as part of the Conditions of Grant Award (National Research Foundation, 2018).

4.4 Intellectual Property

This relates to the protection of the new knowledge, technologies, processes and innovations that emanate from the research that involve the usage of the equipment. All funded researchers must adhere to the intellectual property (IP) policies of the research institution and national government. From a funding agency perspective, ultimate responsibility for the protection of intellectual property rights reside with the institution (National Research Foundation, 2018).

4.5 Data Storage, Usage and Dissemination

This relates to all research outputs that are not protected under Intellectual Property Rights. In such instances, the research outputs, including the source data, need to be made available to the larger research community through an accredited database such as an Open Access repository with the provision of a Digital Object Identifier for future citation and referencing. An institutional data policy needs to be in place, that guides the sharing and access to data that has been generated from the usage of the equipment. If data is stored by users, and not within the vicinity of the equipment, then the data policy of the user's institution needs to be adhered to.

4.6 Payment of Grant

This section outlines the payment mechanisms for grants. Funds, amounting to 80% of the total value of the grant, are released to the research institutions once the institution's senior management and the grant holder have signed off the Conditions of Grant, which must be submitted with the following appendices:

- Updated management plan that makes reference to the institution's risk management strategy as well as addresses issues such as currency fluctuations.
- Updated Gantt chart (refer to Annexure 1).
- Pro-forma invoice for the equipment from the preferred vendor or supplier post the undertaking of a competitive bid process (refer to Financial Management).
- Uploading of an equipment record onto the equipment database which is an online repository of public investments in research equipment (refer to Research Equipment Database).
- Letter of Commitment from the preferred vendor or supplier indicating that the equipment will be operational and functioning at optimal capacity within the timelines specified in the Gantt chart (National Research Foundation, 2018).

The practice of withholding 20% of the grant value, forms part of a risk mitigation strategy by the funding agency. For the final 20% payment to be paid, the following information must be submitted to the funding agency:

- A letter from the supplier indicating that the equipment has been fully installed and commissioned and is working optimally. This letter must be co-signed by the grant holder.
- Project close-out report that is duly signed by the grant holder and the research institution's designated authority (National Research Foundation, 2018).

4.7 Change of Leadership or Institution

Changes management and succession planning forms a key part of grant management for RI investment. In instances, where the researcher retires or resigns from the research institution, one of two scenarios may come into play:

4.7.1 Change of Leadership

In the event of the researcher leaving the research institution either through a resignation, retirement, relocation or other reason, the funding agency must be informed in writing with regard to:

- The alternate arrangements for the continuation of the projects and continued leadership for the management of the equipment at the research institution.
- A replacement researcher who may be the co-applicant on the original application, or another researcher who has the necessary qualifications and experience to manage and maintain the same or similar equipment may be nominated as a replacement researcher by the research institution, and an updated profile in the form of a CV must be submitted to the funding agency.
- Funding will only continue if the funding agency is satisfied that the equipment will be managed and the project will continue at the same level under the replacement researcher.

In such an instance, the appointment of a replacement grant holder must be approved by senior management at the funding agency who have the necessary technical research equipment experience and/or expertise. In cases where specialised facilities are involved, independent expert opinion must be invited prior to a final decision being made by the funding agency (National Research Foundation, 2018).

4.7.2 Change of Institution

The RI grant and the associated equipment may only be transferred to another research institution under extenuating circumstances, which requires the approval of the funding agency. The research institution must be willing to enter into an agreement wherein the research equipment is transferred to another institution which employs the original grant holder, or another research institution that is willing to acquire the research equipment.

In such an event, the following provisions must be met:

- The new institution is a recognised public research institution.
- The new research institution is agreeable to undertaking all conditions and obligations attached to the grant. This means that a new Conditions of Grant must be signed off by the new institution and the appointed grant holder.
- Proof of commitment from the supplier/manufacturer to aid in the relocation process of the equipment, from decommissioning at the original host research institution to transportation, installation and commissioning at the new research institution. All incurred costs will need to be borne by the new research institution.
- A copy of the senate minutes from both research institutions wherein the relocation of the equipment is approved.
- There is a legal agreement between the institutions that describes terms and conditions for the relocation of the equipment including the reimbursement of the cost(s) associated with the procurement, installation and maintenance of the equipment at the original host institution. This arrangement may be facilitated by the funding agency (National Research Foundation, 2018).

4.8 Breach

Should the grant holder or the research institutions fail to meet any of the terms set forth in the Conditions of Grant, then this will constitute a breach. The funding agency can then proceed to (i) halt any further payments of the grant to the research institution; or (ii) withdraw or recall the grant, thereby requesting either the full refund of the funding agency grant or the transfer of the equipment to a more suitable research institution as identified by the funding agency.

In the event of a breach, the funding agency can also proceed to effect further penalties by banning the grant holder and research institution from applying for RI grants for a minimum period of three years or until such time as the terms of the Conditions of Grants have been fully addressed (National Research Foundation, 2018).

4.9 Summary

This section lays the foundation for the sustainable management of RI grants through devolving responsibility and accountability of the management of the funding awarded to a grant holder to the research institution at which he/she is employed. The key elements described in this section aims to minimise both risks and the wasteful expenditures of public funds. In essence, the conditions of grant is a risk management tool that puts in place the necessary mechanisms to safeguard public funds and maximise a return on investment by the funding agency.

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Chapter 5
Skills Required for Managing Research Equipment

Skilled instrument staff ranging from scientists, operators, technicians and engineers can enhance safety, productivity and extend the lifespan of equipment, as well as its components in addition to generating new knowledge and innovation. Skilled staff remains a critical and scarce resource in many countries including South Africa. For instance, discussions across the globe on this subject have revealed that instrumentation staff are not only a scarce skill, but are the hardest positions to fill in any research institution. Considering the scarcity of skillful staff, it becomes increasingly difficult to attract and retain such experts.

5.1 Staff Scientists

Staff scientists are usually responsible for managing labs, facilities (e.g. radio telescope), or specific equipment (e.g. microscopes.) with the intent to acquire new knowledge through research. These experts tend to be academically qualified, typically with a doctoral qualification and tend to be employed on academic grades, such as associate or full professors. In general, staff scientist lead research programmes and investigations, generate data, interpret the data and publish manuscripts. Additionally, staff scientists (i) train students; (ii) pursue grant applications; (iii) generate publications; (iv) develop new innovations, techniques, systems and methodological protocols; and (v) operate and maintain the research equipment.

5.2 Operators

In addition to the staff scientist, an operator plays a key role in managing the research equipment. One of the key roles of an operator is that of training and advising postgraduate students, researchers, postdoctoral fellows and other users on how to utilise

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https://doi.org/10.1007/978-3-030-37281-1_5

the equipment independently in order to answer their specific research questions. Operators usually have a masters and/or doctoral qualification and are normally employed on technical grades as they are able to design and execute methodological protocols using either conventional or advanced techniques or both that best align to the research focus of the user. In addition, the operator's role is to (i) define and optimise the research methodology required to undertake a specific research investigation; (ii) train students, staff and users on how to independently utilise the equipment to generate quality data; and (iii) aid in the analysis and interpretation of the data. The operator may seldom choose to publish manuscripts as a lead author where he/she has undertaken independent research projects. Oftentimes, the operator is a co-author where he/she has made significant contributions towards answering specific research questions posed by staff scientists, other researchers or users through the generation of reliable, innovative and publishable results.

5.3 Technicians

Technicians are responsible for the day-today maintenance, operation and management of the equipment by allocating access-time to various users. They also ensure that the equipment is duly calibrated and configured for usage by each user and that adequate consumables, chemicals and materials are in place for the user to utilise the equipment optimally given the limited access time granted to each user. They also monitor the operational status of the equipment (such as functional, partially functional or non-functional) and performance of systems in consultation with engineers and operators. Technicians may be employed to (i) manage, operate and maintain feeder equipment; (ii) prepare samples for analysis; (iii) report malfunctions; (iv) undertake routine sample analysis; (v) manage the stock of consumables and other materials required for the operating the facility's equipment; and (vi) manage access to the equipment including following up on payment of charge-out rates from users.

5.4 Engineers

The role of engineers is mainly to conduct maintenance, testing and upgrade advanced equipment or control systems, usually in consultation with the operator. Engineers within research institutions may be employed in a highly specialised capacity to (i) diagnose and troubleshoot malfunctions; (ii) replace components and/or parts; (iii) test components and/or parts; (iv) undertake routine maintenance; (v) undertake minor software and other technical upgrades; and (vi) manage and maintain the operations relating to the equipment, including consumables. Sophisticated equipment must have dedicated engineers assigned to ensure optimal functionality at any stage of the equipment lifespan. Most of these engineering-related activities tend to be conducted within the framework of a maintenance plan with the supplier.

5.5 Data Specialists

A data specialist is a fundamental team member in any infrastructure facility. A data specialist can be a technician or possibly an operator or junior staff scientist that possesses strong analytical and problem solving skills. Data specialists have the necessary understanding, competency, expertise and skills required to navigate the cyber-sector. The basis of having such a team member on hand is for the data specialist to assess the value of data, manage that data, make the data discoverable and preserve and store the data so that it can be made useable. In essence, the duty of the data specialist is to (i) analyse and verify data; (ii) design databases or software programmes as part of the data mapping process; (iii) generate reports; and (iv) provide technical support and assistance. A summary of some of the data specialist skills are summarised in Table 5.1.

Each of the critical skills defined and described in this section for instrument staff requires an element of auxiliary discipline-specific training. This is hands-on or practical training for a period spanning 12–18 months and can be considered as an internship-type training intervention that may or may not form part of a curriculum for obtaining a formal degree or qualification. Either way, it becomes a compulsory requirement for an individual seeking to pursue a career path as a staff scientist, operator, technician, engineer or data specialist. Furthermore an auxiliary discipline-specific training programme may not strictly adhere to a strict curriculum format. Rather it provides the individual with the necessary hands on training to develop their skills set further such that they are able to operate at a highly skilled level either as a staff scientist, operator, technician, engineer or data specialist. Essential to the success of any auxiliary training programme is the appointment of a suitably qualified senior experienced staff member as a mentor to the assigned student. An example of auxiliary training in marine studies, includes (i) diving courses; (ii) skipper training or training on how to steer or sail a boat or ship; (iii) training in the use

Table 5.1 Some of the required skills set of a data specialist

People who are experts and
• Operate at a competent level close to the data, and have knowledge of programming and writing codes
• Might have a technical background which includes formal computer training or programming and statistical analysis
• These experts can be either permanent or contracted specialists
People who explore data through statistical and analytical methods
• They know how to assess the data with a view to, for instance, address curiosity-driven issues
• They can build models using data and they are able to code and develop programmes
People who manage, curate, and preserve data
• They are information specialists, archivists, librarians and compliance officers
• If data has value, experts are needed to manage it, make it discoverable, preserve it and make sure it remains usable
• They plan, implement and manage the sourcing, use and maintenance of data assets in line with governance policies, processes and procedures

of mechanical equipment and navigational software, amongst others. The proposed structure of an auxiliary training programme, therefore, ought to focus on the following critical areas of development, with a specific focus on discipline specific research equipment training and management:

- Theoretical training (30%) comprising:
  - Lectures.
  - Assignments that focus on case studies.
- Practical workplace training (70%) comprising:
  - Assignments that focus on practical or hands-on field work.
  - Discipline-specific accreditation courses.
  - Workplace or field work activities.
  - Other relevant training.

A summary of the skills set required for sustainably managing research equipment is presented in Table 5.2.

5.6 Succession Planning

Succession planning is commonly referred to as talent management and development and is the deliberate and systematic effort made by the leadership of organisations to recruit, develop and retain individuals with a range of competencies and skills (Seniwoliba, 2015).

Succession planning is critical for the sustainable management of RI. It is essential that emerging researchers and students are trained and skilled by the current generation of operators, technicians and engineers. The appointment of untrained and unskilled staff can often lead to an increase in costs related to equipment damage, downtime and safety hazards. The downstream implications impact on the quality and quantity of research outputs. Retaining and attracting skilled operators, technicians and engineers is a huge priority for any research laboratory and is also deemed as the hardest positions to fill given the skilled labour shortage globally as described earlier in this section.

Succession planning is an essential process that addresses the depleting size of the talent pool and an aging workforce. Considering the aging workforce of skills RI experties in South Africa, succession planning should be priority for immediate, medium-term and long-term replacement workforce. Facilities need to plan and take firm steps for identifying and training the successor(s) of the aging workforce who face retirement in a minimum period of five years.

Interventions in this area of skills is paramount and must be driven by both the basic education sector in partnership with research intensive institutions. An outline of a structured intervention programme to aid succession planning is presented below:

Table 5.2 Summary of the skills set required to sustainably manage a research equipment facility

	Staff scientist	Operator	Technician	Engineer	Data specialist
Qualifications	Ph.D.	M.Sc. (preferably a Ph.D.)	M.Sc. or honours	B.Sc. in engineering	B.Sc. in ICT and computational statistics (preferably Hons)
Experience	A track record in undertaking independent research and publishing in high-impact journals	A track record in designing and executing methodological protocols using conventional or advanced techniques	A track record in managing, operating and maintaining research equipment	A track record of (i) designing; (ii) testing; (iii) constructing manufacturing; (v) installing; (vi) operating; (vii) maintaining equipment; and (viii) diagnosing and troubleshooting malfunctions on the equipment. Partnering with suppliers is an important activity in this regard	A track record in data manipulation and analysis by selecting the best tools to interrogate data so as to recognise trends that deliver insights to research questions
Auxiliary training	Essential				

- Level 1 intervention at the school level must focus on:
  - Solid foundation at the school level in mathematics, science and physical sciences.
  - Inclusion of an artistic or creative element into the schooling curriculum to support the innovation required in these disciplines.
- Level 2 intervention at the tertiary level must include:
  - Accredited auxiliary training programme courses or internships as an integral part of the curriculum for awarding a degree.
- Level 3 intervention at the workplace must focus on:
  - Appointing mentors and/or coaches to aid the young incumbent along a career path trajectory towards being a skilled staff scientist, operator, technician, engineer or data specialist. The young incumbent is therefore trained to succeed or replace the current staff scientist, operator, technician, engineer or data specialist, at the time of the current employee's retirement.
  - Providing project management training which is critical at the level 3 intervention, for training the incumbent to be assume a management role. Training therefore, must be linked to ensuring the sustainability of a facility and must also extend to include: (i) budgeting and financial management, (ii) planning and forecasting for RI management, maintenance, upgrades or shut down, (iii) building and growing capacity for optimally managing RIs, and (iv) strengthening communication skills such that, the incumbent is able to negotiate price and terms related to maintenance contracts with suppliers.

5.7 Summary

In this chapter, attention is drawn to the essential role of having appropriately skilled and qualified staff trained to optimally and sustainably manage research equipment. This chapter defines the skills and qualifications required to build the human capital development pipeline which specifically addresses staff scientists, operators, technicians, engineers and data specialists. Fundamental to the provisions of this chapter is the development of a robust succession plan to ensure that the critical scarce skills are attracted, trained and retained in the science system.

Reference

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Chapter 6
Monitoring, Evaluation and Risk Management

6.1 Monitoring and Evaluation

Various conceptual frameworks are used to design and structure M&E evaluation criteria. For instance, these include: (i) the logic model, (ii) results-chain framework, and (iii) balanced scorecard approach.

In using the logic model, the following key variables are considered: inputs, outputs and outcomes. The model also considers the logical linkages to external influences, environmental and related programmes as well as the situational context (problem) the motivates the introduction of the intervention (inputs and outputs) to achieve a specific impact (outcome) (Millar, Simeone and Carnevale, 2001). Oftentimes, the logic model is critiqued for being a linear model that aims to monitor and evaluate a multi-dimensional process. When planning to build a logic model the following questions can be posed: (i) what is the current situation that needs to be tackled? (ii) what will it look like when the desired outcome has been achieved? (iii) what behaviours need to change for that outcome to be achieved? (iv) what knowledge or skills do people need before the behaviour changes? (v) what activities need to be performed to cause the necessary change? (vi) what resources will be required to achieve the desired outcome? (Millar et al., 2001).

The results-chain framework on the other hand, is a M&E tool that is used by the World Bank (2012) to measure effectiveness. This framework aims to establish and link strategic development objectives to interventions and intermediate outcomes and results. In developing such a framework that demonstrates effectivess, the following guiding questions can be discussed:

- ***Relevance***
  - Does the programme in its current form respond to national priorities and original objectives?

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https://doi.org/10.1007/978-3-030-37281-1_6

- ***Implementation***
  - What progress has been made in implementing the contractual framework?
  - Were the programme, systems, processes and activities put into place as originally intended?
  - What factors have facilitated and/or acted as barriers to implementation?
  - How can the implementation process of the new contract be improved?
  - To what extent are the strategic objectives for the programme being met?
- ***Effectiveness***
  - Is the programme achieving the goals and objectives it was intended to accomplish?
  - Have the interventions and equipment used produced the expected effects?
  - Could more effects be obtained by using different equipment?
- ***Efficiency***
  - Are the programme's activities being produced with appropriate use of resources such as budget and staff time?
  - Have the objectives been achieved at the lowest cost, or can better effects be obtained at the same cost?
  - To what extent has the infrastructure and workload changed?
- ***Utility***
  - Is the equipment producing satisfactory outcomes with regard to the initial goal from the beneficiary's point of view?
  - Have local working relationships with and within field system changed?
- ***Attribution***
  - Can progress on goals and objectives be shown to be related to the programme, as opposed to other things that are going on at the same time?
- ***Sustainability***
  - Is the programme sustainable? This links to: (i) financial, (ii) human resourcing, (iii) environment, and (iv) research outputs.
  - What quality assurance measures have been introduced? (World Bank, 2012)

The third approach is that of the balanced scorecard. In 1992, Kaplan and Norton proposed the balanced scorecard method to evaluate and measure the financial and non-financial performance of organisations in terms of finances, customers, internal business processes, and learning and growth. The development of the balanced scorecard, therefore, claims to provide a holistic perspective of progress and performance towards achieving strategic goals that allow the organisation to function in a rapidly evolving environment. This multi-perspective method articulates links between inputs, processes and outcomes as well as focuses on the importance of managing these components in order to achieve the organisation's strategic priorities and targets (Kaplan & Norton, 1992). The balanced scorecard has been adopted in the services, manufacturing, marketing and retailing, and public sectors (Hoque, 2014).

The choice of the most suitable M&E tool depends on its fit with the organisation's mandate and its strategic imperatives. This means that based on the maturity of the organisation and the systems and processes that are in place, the choice of the M&E tool may differ.

6.2 Site Visits and/or Technical Audits

An integral component of monitoring and evaluation of equipment grants is a site visit and technical audit as conducted by funding agencies at the time at which the equipment is pronounced to be commissioned by the grant holder and the research institution's designated authority. This entails the visit of public agency staff to the location at which the research equipment has been installed and commissioned with the objective of assessing:

- All management plan criteria and requirements are met.
- The functional capability of the equipment in terms of the equipment yielding results that meet publication or journal standards.
- The quality and quantity of outputs linked to the usage of the equipment.
- The usage of the equipment by (i) postgraduate students; (ii) other researchers, both national and international; and (iii) private sector.

In cases where any of the above criteria are not met then a full technical audit will need to be conducted. This would firstly entail the submission of an audit report by the supplier, highlighting the following:

- Have the manufacturer-specified environmental conditions for housing the equipment been met? If there are gaps in meeting any or all of the specified conditions as described in Chap. 7, then these must be stated.
- Are there are any challenges that relate to either the hardware or software? If hardware, is reported as a challenge then the supplier must indicate if the replacement components are covered by the guarantees and/or warranties of the service level agreement.
- Are there gaps in the skills set at the institution, in terms of optimally operating the equipment?

Secondly, based on the audit report from the manufacturer, the institution must be able to respond in writing to the report. The final report must be submitted to the funding agency and must consider the following requirements:

- Steps that will be taken to address the gaps identified.
- Timelines for delivery.
- Available budget for the implementation of the above.

Thirdly, a face-to-face meeting must be convened comprising the following parties:

- Technical audit team comprising representatives from the funding agency, including (i) staff responsible for managing the RI grants; (ii) internal auditors; (iii) financial grants management staff; and (iv) an independent research equipment expert.
- Research equipment team comprising of (i) senior management representatives at the research institution; (ii) the grant holder; and (iii) the supplier and/or manufacturer of the equipment.

The objectives of such a meeting focus on:

- Reaching consensus and recording the agreements, committed budgets and timeframes for implementation.
- Engaging the supplier and/or manufacturer on how best to expedite the process for addressing the gaps and/or challenges. This may include defining the role of the supplier and/or manufacturer in aiding the grant holder to resolve these challenges.
- Engaging senior management and the grant holder of the research institution on meeting the agreed to deliverables.

In the event that there is a lack of commitment or adherence to the timelines and/or deliverables in the management plan the funding agency is liable to make reference to the breach clause in the Conditions of Grant and to proceed to either withdraw or recall the grant awarded to the institution as described in Chap. 4.

6.3 Risk Management

Funding agencies need to manage risks on a daily basis, especially relating to financial controls and integrity (Bailey, 2010). These organisations need to guard against falling prey to managing risks in a haphazard and unsystematic manner. In this section, the term “risk” is used to describe event(s) that have a potentially negative impact on the funding agency’s assets, activities and operations (Kwak & Keleher, 2015). The management of risks and risk events refers to the (i) continuous process of assessing risks; (ii) reducing the chances of a risk event transpiring; and (iii) putting in places measures to tackle an event should it occur (Kwak & Keleher, 2015). The mapping of potential risks and the impact of risk events against the likelihood of such events transpiring, forms part of a risk register, and is an important risk management exercise (Bailey, 2010). Hence risk management must commence at the RI planning phase.

Part of risk management relating to research equipment involves the planning related to minimising loss (financial and other), damages, and impact of acquired physical assets from third party allegations of liability. Information presented in this section makes reference to the work done by Bailey (2010) and Kwak and Keleher (2015). There are six components identified as part of the risk management process which includes the (i) internal environment; (ii) objective setting; (iii) event identification; (iv) risk assessment and response; (v) control activities, and (vi) communication and monitoring (Bailey, 2010).

One of the suggestions of Kwak and Keleher (2015) is to adopt enterprise risk management (ERM) as a tool to manage risks and exploit opportunities. The rationale for using ERM is that it affords organisations, particularly funding agencies, the ability to identify and assess threats or risk events in terms of the likelihood of such an event transpiring and the magnitude of impact should the risk event occur. A further suggestion is that the funding agency develop new internal policies in support of the ERM and that for risk management processes to be effective existing data sources must be utilised whilst simultaneously considering the incorporation of new ones. In the way of recommendations, Kwak and Keleher (2015) propose that funding agencies utilise data-driven systems to collect and manage data which in turn can be utilised to assess risks—such data may include historic data on the grant holder in terms of historic number of grants and size of grant values, performance and other monitoring data. Another recommendation that the investment in the introduction of new or revised risk management practices be supported by parallel investments in training and capacity development interventions. These in turn can inform tools and processes to standardise the decision-making and decision-approving process within the funding agency (Kwak & Keleher, 2015).

In addition, risk management must be an iterative process across the four stages of the grant lifecycle. Within each stage of the grant lifecycle, risk events have the possibility of materialising and funding agencies need to be proactive in preparing for such threats. For a detailed implementation framework of risk refer to Annexure B.

Usually risks can be minimised through institutional insurance cover that extends to instances where there may be theft or breakage of equipment and the associated loss of research data. Hence part of the planning process may take into consideration the following:

- What will be insured?
- At whose cost?
- What are the options for public liability cover?
- What are the options for professional liability cover?

In safeguarding the funding or investment from any risks, it is imperative for the funding agency that is awarding the grant to stipulate the conditions associated with that grant award. This is a legally binding document that is issued by the funding agency and is consented to and signed by the researcher and their research institution's designated authority.

As part of a risk management process, one of the recommendations by Kwak and Keheler (2015) is for a business unit for risk management services to be established. This unit ought to comprise of (i) a policy team that drafts policy and provides technical assistance to staff at the funding agency; (ii) management improvement team that focuses on providing assistance to grant holders on matters relating to grants; and (iii) a programme monitoring team that concentrates on monitoring and evaluation activities as well as measuring performance against KPIs. This team also focuses on standardisation of the collection and review of data (Kwak & Keleher, 2015).

In order to manage risks relating to large investments in RI, a requirement from the side of the funding agency would be to put in place a governance and management structure at the host research institution. Based on experience, it is imperative to have a two-layered governance structure. The first layer will primarily (i) have an advisory role; (ii) ensure good governance; (iii) commit to the provision of the necessary resources required to meet obligations and conditions relating to the equipment, including risks relating to currency fluctuations; and (iv) review performance and budgets. This first layer can be termed the advisory committee and may comprise of, but be not limited to, representatives from (i) senior management at research institutions; (ii) the funding agency; (iii) private sector or other donor parties if they have contributed in some form to the cost of acquiring the research equipment; (iv) public outreach sector; (v) operations management; and (vi) independent experts.

The second layer, or operations committee, may comprise of, but not limited to, representatives from (i) the user community; (ii) the researcher to whom the equipment was awarded; (iii) staff scientists, operators, technicians, engineers and data specialists; and (iv) the finance officer. The operations committee will be responsible for (i) the day-to-day management of the facility; (ii) reporting on usage of the equipment, income and expenditure, and research outputs; (iii) develop an access and research strategy for the research equipment facility; and (iv) submit statutory reports that are required by the funding agency.

6.4 Reporting

Funding agencies such as the NRF tend to measure performance against the two said indicators, viz. financial and non-financial indicators, as described by the balanced scorecard approach to M&E (National Research Foundation, 2018b). A summary is presented in Fig. 6.1.

- **Financial indicators**

One of the financial indicators that the NRF measures performance in this perspective, is against the financial spend of grants awarded to grant holders (National Research Foundation, 2018b). This means that the NRF measures performance against grant funds being claimed or drawn by the grant holder. Usually funding agencies face the challenge of poor uptake of grants by institutions due to challenges associated with procurement processes amongst others (refer to Chap. 7). Consequently there is a large cash holding of funds committed to grants that reside with public funding

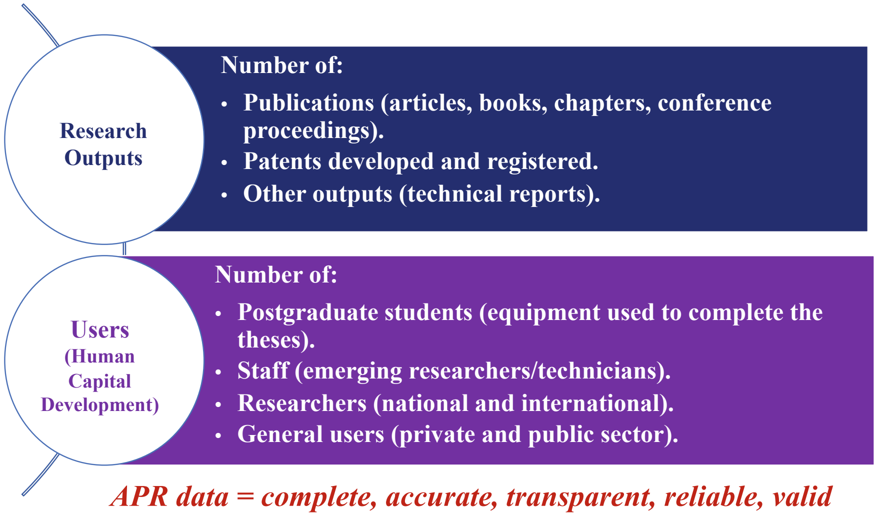

Fig. 6.1 Return on RI investments, as measured by financial and non-financial indicators, must reflect accuracy, completeness, transparency validity and reliability

agencies. Hence, the facilitated movement of funds from funding agencies to grant holder institutions is a measure of performance against the financial indicators.

- **Non-financial indicators**

Data received by the NRF is usually sourced from annual progress reports (APRs) that are submitted by the grant holder on an annual basis (National Research Foundation, 2018b). This data must be checked by the institutional management that information presented to the funding agency is: (i) accurate; (ii) complete; (iii) valid; (iv) reliable; and (v) transparent, in accordance with Sect. 4.2 above. This quality assurance check ensures that collated and consolidated information is accurately reported by the funding agency against both financial and non-financial indicators. The non-performance indicators within the NRF context extends firstly to outputs linked to human capital development, which in turn counts (i) the number of users linked to the placement of an equipment; and (ii) the number of postgraduate students trained on using the equipment. The second non-financial indicator links to research outputs, viz. (i) number of publications; (ii) number of patents; and (iii) other research outputs (National Research Foundation, 2018b). These indicators are expanded, as follows:

Human capital development

- *Number of postgraduate students trained*: A reflection of how many Master's and Doctoral students have obtained degrees where they utilised the research equipment.
- *Number of users*: A reflection of usage of the equipment by the wider research community.

- *Staff and researcher development*: A reflection of capacity development for training instrument staff and researchers, both at the home institution as well as other research institutions. This also links to the concept of succession planning.

Research outputs

- *Number of publications:* A reflection of the productivity linked to the usage of the equipment.
- *Number of patents*: A reflection of the innovative capacity linked to the usage of the equipment.
- *Other research outputs*: A reflection of other novel areas of productivity linked to the usage of the equipment. These may extend to invited plenary talks at national and/or international meetings that links to the research equipment.

Based on the annual reports submitted by the recipients of RI grants, over the period spanning 2009–2017, the outputs have been reported in Table 6.1.

Of the total number of RI grants awarded by the NRF, 301 grants (approximately 74% of a total number of 408 grants awarded) were able to support the priority investment areas in the country spanning (i) Farmer to Pharma; (ii) Space Science; (iii) Energy Security; (iv) Global Climate Change; (v) Water Security; and (vi) Human and Social Dynamics. The remaining, 26% of grants were in support of blue skies research in areas such as nanotechnology and biotechnology, amongst others (Table 6.2).

6.5 Equipment Database

The development of a national research equipment database is a critical enabler for the effective management of research infrastructure grants by any funding agency. Such a database fulfils the role of an online repository that houses relevant information pertaining to investments across the various RI categories that have been procured using public funds. The database hosted by the NRF, the Research Equipment Database (RED), is a live tool that plays an important role in:

- Informing a funding agency of continued investment(s) in research equipment and platforms.
- Advising the researcher community of what equipment is available nationally.
- Facilitating access by researchers and students to multi-user equipment.
- Stimulating new applications to the funding agency for research infrastructure (National Research Foundation, 2018a).
- Minimising the duplication of equipment within a specific institution, region or country.

Table 6.1 Outputs against research infrastructure grants awarded by the National Research Foundation from 2009 to 2017* (National Research Foundation, 2018a)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total
Total number of users	1918	2275	3403	2210	2474	1652	2471	2937	2881	22,221
Journal articles	678	463	683	838	882	400	1027	614	552	6137
Books/book chapters	12	11	7	72	54	19	78	1	11	265
Patents	15	24	63	22	72	32	15	3	4	515

*At the time of publication, 2018 output data had not been published

Table 6.2 Priority areas that have been supported through research conducted on equipment grants awarded by the National Research Foundation (2018a)

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
Farmer to Pharma	8	14	15	13	19	15	14	15	No grants were awarded	11	124
Space Science	7	14	6	10	13	13	23	9		2	97
Energy Security	8	5	10	5	3	8	0	0		2	41
Global Climate Change	2	2	1	3	2	4	0	4		3	21
Water Security	1	1	2	1	2	4	0	1		1	13
Human and Social Dynamics	2	1	0	1	0	0	0	0		1	5

The database should house information that would allow one to adequately gauge the:

- Type of equipment.
- Model of the equipment.
- Functional state of the equipment.
- Disciplines supported by the equipment.
- Geographical location of the equipment (name of the research institution, the department and the laboratory space/building the equipment occupies).
- Contact details of the person in charge of the equipment who would facilitate access to various users (National Research Foundation, 2018a).

Such a database is able to map the type of research equipment available within a country and how this is distributed across the national landscape with the secondary objective of minimising the duplication of investments at institutions that are in close proximity. It serves as an analytical tool that allows funding agency staff to update content and also track the outputs, outcomes and impact relating to the investment in research equipment.

6.6 Summary

This chapter presents an overview of monitoring and evaluation aligned to the management of research infrastructure. Furthermore, the chapter makes reference to pertinent issues such as risk management, reporting, site visits and technical audits. This chapter also recommends the development and maintenance of a database that can serve as a central repository of RI grants within a specific country.

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Chapter 7
The Sustainable Management of Research Equipment

The critical aspects of a robust management plan includes the: (i) physical infrastructure; (ii) services and utilities; (iii) safety and security; (iv) insurance arrangements; (v) alternate power supply; (vi) maintenance; (vii) access and training; (viii) having appropriately skilled instrument staff in place, and (ix) a clear data management plan (Fig. 7.1). From the aspects highlighted above, the following key areas must

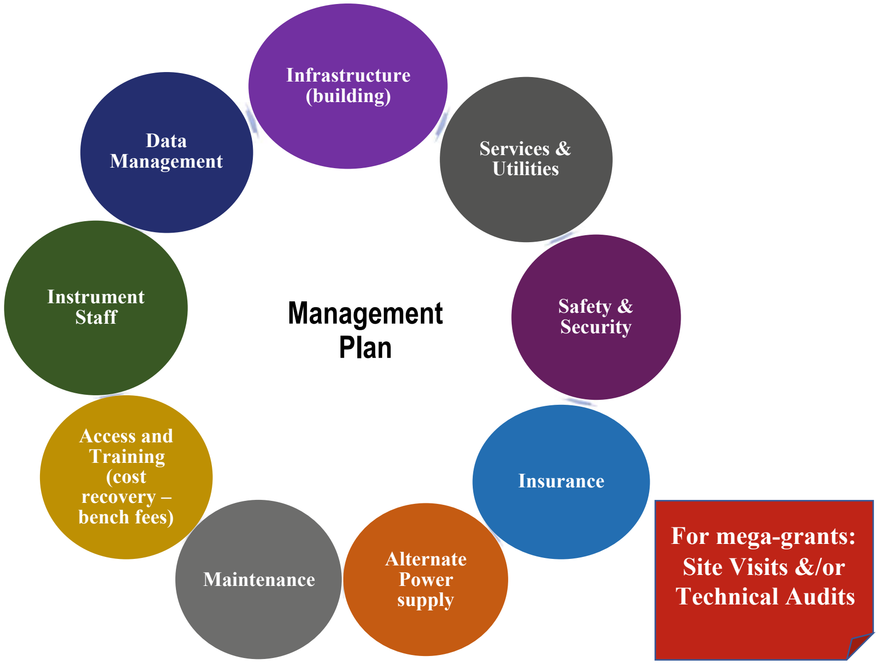

Fig. 7.1 Key elements of a robust management plan (National Research Foundation, 2018b)

R. Ramoutar-Prieschl and S. Hachigonta, *Management of Research Infrastructures: A South African Funding Perspective*,
https://doi.org/10.1007/978-3-030-37281-1_7

be drilled into: (i) human resourcing for attracting, retaining and upskilling appropriately trained and competent instrument staff; (ii) maintenance including services and utilities; (iii) compliance with governance structures; (iv) financial sustainability; (v) optimal utilisation and access to the equipment; (vi) infrastructure to house the research equipment; and (vii) data management (Fig. 7.1). This management plan must be defined and described in detail in partnership with the selected and/or preferred supplier. At all stages herein, the supplier must be duly consulted. In addition, this plan must have a dedicated budget and resources. The best manner in which to address these dimensions of a management plan is through the use of a Gantt chart (refer to Annexure A).

7.1 Human Resourcing

The critical human resource personnel associated with the management and maintenance of RI, as highlighted in Chap. 5, include staff scientists, operators, technicians, engineers and data scientists that are available to operate, manage and maintain state-of-the-art research equipment and the data that is consequently generated from its usage. The human resourcing linked to the effective and sustainable management of research equipment is dependant on the level of skills, experience and track record of the team who manage the equipment. With appropriately skilled and experienced staff appointed the transition time and training needs are minimal, especially, if the institution is able to negotiate with the supplier to train a resident or in-house engineer resulting in efficient oparation of the equipment. The ability and experience of skilled staff to fully operate and maintain research equipment further accrues cost and time savings in terms of the training and support requirements from both the institution and supplier. Fundamentally linked to the sustainable management of research equipment is the identification of an academic champion that drives the research programme around the use of the equipment. Staff scientists are able to ensure that the equipment can be utilised to address a multitude of research projects across a number of disciplines that can be supported by the equipment. As much as there is a need to ensure that the appropriately skilled and experienced staff are in place, there is also the need to ensure that there is a plan to transfer these skills and training to the next generation of emerging researchers. Upskilling these researchers will allow for increased usage of the facility which will not only accrue revenue to offset the cost of managing the facility but also contribute to developing the human capital pipeline in an area that is deemed a scarce skill.

7.2 Maintenance of Systems

This section makes specific reference to service level agreements and/or maintenance contracts with the selected supplier and/or manufacturer and includes warranties and guarantees on the system as a whole as well as individual components and parts. In establishing a home for the research equipment, the role of the supplier must not be underestimated. Before the installation of new or upgraded research equipment, related or supporting materials, equipment and reagents must be procured. In addition, it is imperative to have a clear understanding of the full list of services and provisions that are either included, excluded or deemed optional in the contract with the supplier. Defining the type and nature of support includes specifying any special terms and conditions that may be applicable to a specific research equipment and/or its geographical location. Some of the questions that may need to considered are as follows:

- Will the agreement cover preventative as well as remedial maintenance?
- What is the specified number of preventative and remedial activities scheduled in the contract?
- What software products and services are defined in the agreement?
- Will the scheduled preventative and remedial maintenance include the upgrade of the operating software and services?
- What is the duration of the contractual arrangement?
- What are the supplier's policies for the maintenance and support?
- What is the supplier's standard cover and charges?
- Will the standard cover be sufficient for the grant holder? What are the costs related to extended cover?
- What are the annual increases of inflationary costs that the grant holder and research institution need to plan for?
- Are there limits on parts or labour costs in the agreement?
- Will the machines be serviced by technicians and engineers that are locally based or based at the manufacturer's facility abroad? In the latter case, would the supplier make available replacement equipment to the grant holder?
- What is the maximum turnaround time for resolving system-related challenges if a technician or engineer has to travel from abroad? A major challenge that is faced by countries in the global south is that research equipment is procured from suppliers and/or manufacturers that are usually based in the global north, specifically from the European Union or the United States of America. Hence, if there are problems with a system or if a component is damaged and needs to be replaced, then this query is logged against a global list of queries, leading to a longer equipment down-time resulting in low productivity. This has a cascading effect on research publications and other outputs as well as time needed for completing postgraduate qualifications. The turn-around times to resolve any system challenges must, therefore, be discussed and specified in the contractual arrangement with the supplier. This high impact risk can be minimised to some extent,

by the supplier training a resident or in-house engineer on how to manage and maintain the research equipment.

7.3 Infrastructure to House Research Equipment

The infrastructure required to house the research equipment includes other infrastructural pre-requisites that are essential for the research equipment to be able to function according to its technical specifications. Addressing this dimension requires the manufacturer and/or supplier to co-operate with the researcher and the research institution in evaluating the geo-technical suitability of the geographical site selected to house the system and making recommendations on how best to address environmental challenges. In addition, the manufacturer and/or supplier plays a vital role in specifying and defining the environmental conditions as well as the requirements for constructing a new building or refurbishing an existing building so that the optimal functionality of the system is ensured. Trains, wave motion of the ocean and elevator shafts, to name a few, have all been implicated in some form or the other to either partially for fully impacting on the functionality of the equipment by creating interference to the system. Cancellation/filtering system(s) need to be in place that allow for the functionality of the system to be at its most optimal given the challenges linked to the geographical location of the research equipment. Again, this would require the expertise of the manufacturer and/or supplier in identifying the most appropriate cancellation/filtering system(s).

In addition to the building and geographical location, utilities and services need to be considered when defining the housing requirements for research equipment. This includes putting in place an uninterrupted and backup power supply in case of power failures which may cause unnecessary complications, including short circuiting within critical components of the research equipment at the time of a power surge. This can cause problems relating to the functionalities of certain components of state-of-the-art research equipment such as laser beams which, in turn, can lead to measurement errors, if the equipment is not recalibrated. Other supporting infrastructural requisites may include feeder research equipment being put in place to enhance the operational capacity of the research equipment. For example, a Focused Ion Beam Scanning Electron Microscope (FIBSEM) is an essential pre-requisite feeder research system that would be needed to prepare inorganic, organic and biological samples of a homogenous geometry and thickness. Such homogenous samples would facilitate a more accurate, useful and meaningful sample characterisation and analysis when using the High Resolution Transmission Electron Microscope (HRTEM).

7.4 Access Strategy

An access strategy needs to be defined in order to facilitate open and wide access, which must be driven by excellence as measured by the scientific merit of research proposals that are submitted by current and potential users of the equipment. This includes taking into consideration and planning for private sector usage which in turn can be charged at a premium hourly rate for equipment usage. Access rates can, therefore, be differentiated according to the various categories of users, which include, but is not limited to, the grant holder, students, postdoctoral fellows, intra-institutional collaborators, other researchers and the private sector. Having an access charge-out rate is a necessary tool for the researcher managing the equipment to be able to accrue some revenue that can aid in off-setting some of the cost(s) related to day-to-day operations.

The Food and Agriculture Organisation of the United Nations (1992) has put up guidelines for calculating machine rate, charge-out fee. It is recommends that these costs should be classified in terms of fixed, operating and labour costs. All three types of costs need to be considered when determining the minimal charge-out rate for usage of equipment. Fixed costs are those costs that can be traced directly to the usage of the equipment such as depreciation on the research equipment; interest on investment or loan(s); taxes; storage of data; backup systems such as UPS; and insurance (Food and Agriculture Organisation of the United Nations, 1992). In most instances, depreciation is not factored into the calculation of the user rates for researchers as it will significantly inflate the charge-out rate, but depreciation must definitely be considered when calculating commercial rates for the usage of research equipment by the private sector. Operating costs relate to those costs that are incurred from operating the research equipment in order to generate reliable data. These costs include computer costs; software licences; service and maintenance contracts; consumables (including direct and indirect materials and supplies); rental costs for the space where the equipment is placed; utilities such as electricity and water; equipment maintenance; and repairs (Food and Agriculture Organisation of the United Nations, 1992). Labour costs are those costs that are associated with the employment of the staff that manage and maintain the research equipment. It directly links to the proportionate salary of these staff members, spent on a project, including benefits linked to their salary packages such as medical aid and pension fund, amongst others (Food and Agriculture Organisation of the United Nations, 1992). Collectively, these three types of costs can be converted into an hourly rate that will then be used as the minimal charge-out rate for accessing and using the research equipment. The formula utilised to calculate charge-out rates differ across the various types of research institutions and countries. Hence it best to solicit the advice and expertise of a financial or asset manager in calculating an appropriate charge-out rate.

7.5 Data Management and Its Preservation

This section reflects on the management and preservation of the four “Vs” of data, viz. (i) volume; (ii) variety; (iii) velocity; and (iv) veracity (Hey, Tansley, & Tolle, 2009). The section links to the specialist skills, as described in Chap. 5, required to navigate this niche area. Data management and its preservation is essential to the long-term sustainability of research equipment. Data management relates to the management of information through its lifecycle from creation and storage to it becoming obsolete, at which stage information is deleted. Advanced technologies, along with data intensive research, are multiplying the volumes of data in all scientific disciplines. In addition, the increase in data generation stems from billions of people using digital and smart devices and social media services from research, digitised literature and archives to public services at hospitals and land registries (European Commission, 2016). Big data sets and their management is no longer an issue that relates to data intensive disciplines but has become an everyday challenge in many areas of life. Therefore, the administration and governance of large volumes of both structured and unstructured data, which may involve terabytes or even petabytes of information, need to be understood across various dimensions. This is imperative for ensuring the translation of open science into open innovation that creates value by addressing societal needs.

The research data management lifecycle comprises of data (i) creation; (ii) processing; (iii) analysing; (iv) preserving; (v) access; and (vi) re-use (University of Essex, 2017). Efforts must be undertaken to develop the necessary digital infrastructures for data generation and dissemination, for storage and analysis with the objective of ensuring that the ideal conditions are met for the undertaking of excellent research (European Commission, 2016).

The creation of data usually entails: describing the research design, data management plan (format, storage, security and consent for sharing), locating existing data, collecting data, and capturing and creating metadata. Data processing includes transcribing, translating, digitising, validating, anonymising, describing, managing and storing data. Data analysis refers to the interpretation and derivation of data, as well as the preparation of data for its preservation and storage. A product of this phase of the research data management lifecycle is the generation of research outputs such as publications. Data preservation requires the migration of data to the best format in a suitable medium where it can be backed-up and stored. Integrally linked to data preservation is the creation of metadata and documentation as well as the archiving of data. Once the above phases of the data management lifecycle have been addressed, measures must be adopted for ensuring researcher access and re-use of the data. The former requires the distribution, sharing, promotion, controlled access and establishment copyrights to the data. The latter entails undertaking research reviews, follow-up research, new research, and usage for the purpose of teaching and learning (University of Essex, 2017). The decision to either preserve or dispose of data ought to be made up front during the planning stage. If data is to be preserved then it must be stored with a clear open access policy that adheres to specific traceability as well as national, social, economic and regulatory arrangements (Organisation for Economic Co-operation and Development, 2007). In accessing data, the concept of data citation gains increasing relevance, which is the practice of providing a reference to data in the same way as researchers provide a bibliographic references to research publications (Corti, van den Eynden, Bishop, & Woollard, 2014).

The access to data accrues the following benefits: (i) increases the returns from public investment in research; (ii) reinforces open scientific inquiry; (iii) encourages diversity of studies and opinions; (iv) promotes new areas of research; and (v) enables the exploration of topics not envisaged or thought possible by the original researchers (Organisation for Economic Co-operation and Development, 2007). Open access to research data from public funding should be easy, timely, user-friendly and preferably internationally available in a transparent manner, ideally via the internet. The European Cloud Initiative advocates for the sharing of data and developing a trusted open environment for storing, sharing and reusing scientific data and results (European Commission, 2016).

Access may only be restricted or limited in the following instances relating to (i) national security; (ii) privacy and confidentiality relating to the data on human subjects and other personal data; (iii) trade secrets and intellectual property rights, usually derived from engagement(s) with private enterprise; (iv) protection of rare, threatened or endangered species; and (v) data under consideration in legal action(s) (Organisation for Economic Co-operation and Development, 2007). If data is to be disposed then files should be deleted after they have fulfilled their purpose.

The research data management lifecycle achieves increasing levels of complexity when large data volumes are involved. Large data volumes are synonymous with big data commonly associated with the usage of dedicated large research infrastructure facilities, such as GRIs, that require multinational investments and are utilised by large collaborative networks (Bicarregui et al., 2013). One of the key challenges in managing big data includes the undisciplined and unstructured manner in which disparate data is generated, mined and managed by a variety of independent researchers. Such anarchy requires a governmental and inter-governmental policy framework to guide the generation, preservation, storage, access and re-use of large data volumes (Bicarregui et al., 2013). Such a policy framework would also address key issues such as (i) ownership of data; (ii) open data; (iii) disposal of data; (iv) data mining; (v) data security, amongst others. Ownership is a rather sensitive topic—in a number of instances, where the research was funded with public funds. The common practice by public funders is to ensure, through the Conditions of Grant, that scientific data is made universally available for research purposes. This practice of open access aims to improve and maximise access to and re-use of research data, including its verification. Linked to general data release is an ethical dilemma which must be explicitly defined along with mitigation steps in a policy framework. The ethical dilemma links to the process of data mining, otherwise termed knowledge discovery in databases, which forms part of the knowledge discovery process. Data mining relates to the extraction of potentially useful, yet unidentified, information from large volumes of data that reside in different databases (Singh & Swaroop, 2013). This is particularly useful in research relating to national defence and security initiatives.

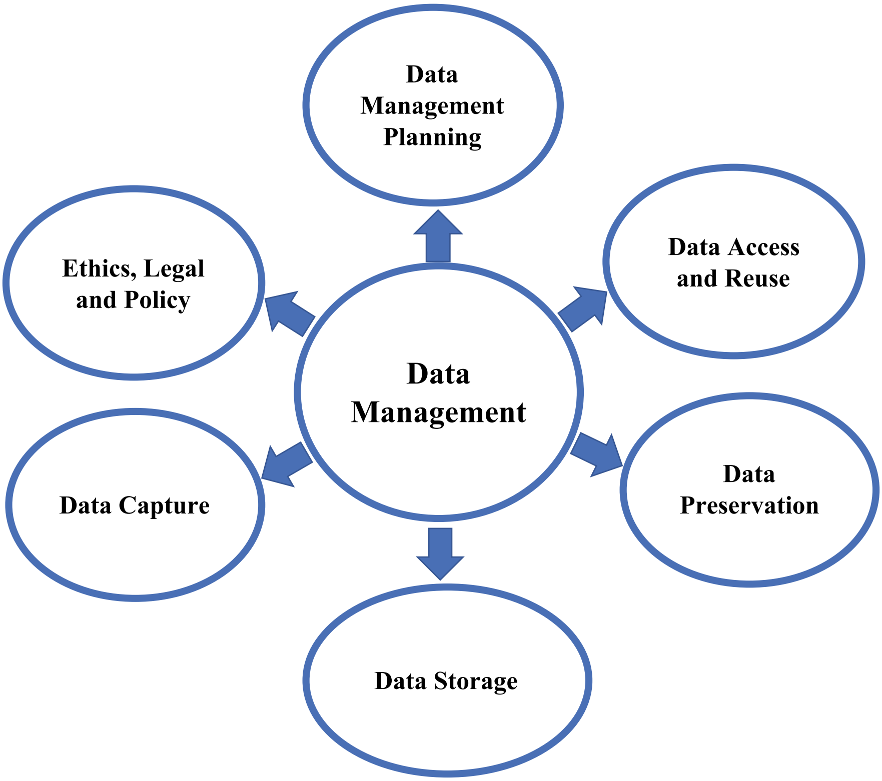

Fig. 7.2 Summary of data management lifecycle

The challenge that arises when personal and/or sensitive data is accessed for analysis and publication as this violates the privacy of individuals whose data is referred to. Methodological and/or statistical approaches must, therefore, be employed to ensure privacy and security of personal information in the data mining process (Singh & Swaroop, 2013) (Fig. 7.2).

7.6 Financial Management

Financial management takes into consideration the full cost(s) relating to the management of the equipment over its lifespan, including its exit strategy. Revenue streams, which includes, but is not limited to access rates, need to be explored and properly planned to ensure that the cost of the daily operations linked to the equipment is affordable to the researcher, the department and the research institution. Financial resources are the primary drivers for a well-managed and sustainable equipment management plan—it is the critical enabler for ensuring timeous delivery relating to

(i) buildings and refurbishments; (ii) procuring equipment; (iii) forward cover and other insurance related matters; (iv) service contracts; (v) utilities; (vi) consumables; (vii) software upgrades; (viii) data management; (ix) staffing costs; and (x) logistics and administration. An efficient financial system and administrator would (i) ensure that accounts are in order; (ii) facilitate the collection of late payment of invoices; and (iii) manage other administrative issues such as contacting service engineers, tracking the duration of service contracts, amongst others.

Essential to this process is defining in detail the specifications of the research equipment or system that the researcher would want to procure that meets their research needs. This is a precautionary measure that would close any gaps relating to any hidden costs that may need to be covered by the researcher or the institution at a later stage due to ambiguity or a lack of clarity. Specifying the capabilities, peripheral system and other components of the research equipment must be driven by the research need(s). It is not simply a matter of a single research system servicing the needs of a diverse group of researchers, as is the case with many instruments that are placed in central analytical facilities. The challenge of specifying the requirements of a research equipment is that it must cater for the specific research needs of the researcher. The more specialised the equipment the less likely it is to address a multi-disciplinarily focus. An example is that of a Transmission Electron Microscope (TEM) that is optimally designed to address the research needs of materials scientists which includes a high accelerating voltage electron beam in order to preserve the rather fragile material. Such a system is unable to optimally cater for the needs of biologists that require a cryo-chamber and a lower voltage electron beam. Hence, in order to address the very diverse research needs of both disciplines, hybrid systems would need to be specified and subsequently developed. This hybrid system will not optimally benefit research in either discipline as the discipline-specific specifications on the system will always have to be comprised in order to cater for the research needs of the other discipline(s). Such sub-optimal hybrid system specifications hinder to some degree the discipline-specific process of scientific inquiry.

Consideration must therefore be afforded to both the immediate and possible future projects that can be undertaken utilising the research system. This implies that the specifications of the research equipment must lend itself to include possible upgrades at a later stage that would cater for the researcher's evolving research needs. Caution must be employed to ensure that a "wish list" is not put forth that goes beyond the researcher's immediate and foreseeable needs, expertise and skills set. In sourcing the best price, it is best to consider either going on an open tender to solicit the best supplier (vendor) or to at least obtain three competitive written quotations for the system that the researcher has fully specified. Against the backdrop of good governance and transparency, a supply chain processes (SCM) must be undertaken. The processes and methods of procurement are summarised in Table 7.1 which is extracted from the Public Finance Management Act (South African Department of Finance, 1999).

In many instances, the procurement of research equipment requires the employment of competitive bid processes, as the costs tend to exceed R500,000. This therefore means that the following committees would need to be constituted:

Table 7.1 Procurement method to be employed per monetary threshold

Monetary threshold values for goods, services, and works	
Value	Procurement method
R0 to R2000 per case (VAT included)	• Follow the petty cash procedure noted in the supply chain management (SCM) policy • No capital assets, consultants or items available on contract may be purchased through petty cash
R0 to R10,000 per case (VAT included)	• Follow the minimum three "verbal or written quotation" process • Official order should be placed against a written quote from the service provider
Above R10,000 to less than R30,000 per case (VAT included)	• Follow the minimum three "written quotation" process • No need to apply the preferential procurement policy framework management act (PPPFA)
R30,000 to R500,000 per case (VAT included)	• Follow the minimum three "written quotation" process • Apply the PPPFA and the 80/20 principle • For all procurement greater than R30,000, obtain a valid tax clearance certificate from the service provider
Above R500,000 per case (VAT included)	• Follow the competitive bidding process • Apply the PPPFA and the 90/10 principle

Source South African Department of National Treasury (2000)

- **Bid Specification Committee (BSC)**: Constitutes a group of technical experts that have experience using the same and/or similar research equipment. This committee must include a supply chain practitioner. The fundamental responsibility of the BSC is to compile the specifications for the type of research that would benefit from the procurement and placement of the research equipment. Included in the specifications is a scorecard that defines the evaluation dimensions against which potential service providers/vendors will be measured. Once the specifications and scorecard have been defined, a process of open solicitation of proposals and written quotations is undertaken using various media, such as newspapers, online advertisements, amongst others (South African Department of Finance, 1999).
- **Bid Evaluation Committee (BEC)**: Constitutes a group of individuals that will evaluate all the solicited proposals and quotations against the specifications and scorecard that were defined by the BSC. This committee must include a supply chain practitioner. This committee may comprise a maximum of two representatives from the BSC. The responsibility of the BEC is to recommend to the Bid Adjudication Committee the service provider/vendor that offers the best value for money after all relevant factors, including cost, have been considered (South African Department of Finance, 1999).

- **Bid Adjudication Committee (BAC)**: usually comprises the Chief Financial Officer from the research institution as chairperson of the committee, as well as other nominated senior officials, including a supply chain practitioner. This is an independent committee that is composed of different members from those serving on the BSC and BEC to ensure a fair and transparent process. The task of this committee is to consider the (i) processes undertaken to solicit proposals and quotations in line with the SCM policies and procedures; and (ii) consider the recommendation of the BEC, prior to making the final award (South African Department of Finance, 1999).

A summary of the SCM processes is presented in Fig. 7.3. At any stage, should a conflict of interest be recognised and/or declared, then that conflicted member would need to recuse themselves from a sitting committee.

Once a supplier has been identified in line with the institution's SCM processes, the *negotiation of the terms and conditions of the service contract* for the research equipment commences. This contract would ultimately be signed off by the management staff at both the research institution and supplier's and/or manufacturer's offices. In the South African context, it has been found that research institutions face numerous challenges in managing service contracts with suppliers of research equipment. The key is not to sign the standard service contract template but to consider customising the contract to meet the needs of the research institution and the

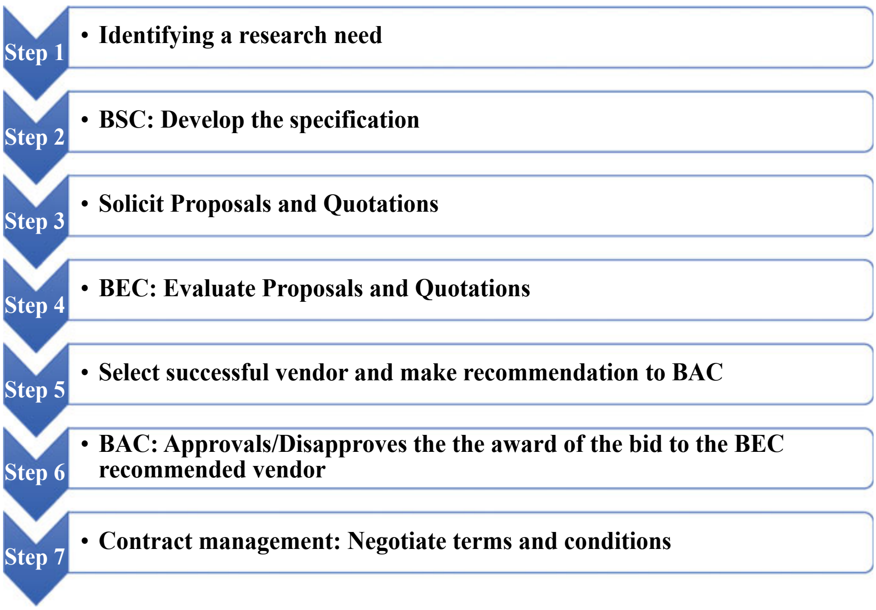

Fig. 7.3 Summary of the SCM processes

skills level(s) of the researchers and staff managing and maintaining the research equipment at a specific institution.

This would then inform the nature of the level of hands-on support and training required from the supplier as well as their response time to any query or instrument malfunction. Hence, clear roles, responsibilities and turn-around times need to be clearly articulated within the service agreement. When parties enter into an agreement they have to determine the costs related to the provision of services over and above that which accompanies a standard contract. One shoule never assume that the amount mentioned in the contract is correct even if it was done by the procurement or finance office—it is always recommended to check for errors, especially where formulae and equations are used and detailed.

The following should be considered when negotiating a service level agreement or maintenance contract with a supplier:

- The parties need to determine the time intervals at which costs are calculated, for example hourly/weekly or monthly basis.
- Is the costed amount inclusive or exclusive of VAT?
- What happens when overtime is worked by supplier staff in resolving issues with the research equipment?
- What currency will be applicable? Currency exchange rate may have to be considered.
- The parties also need to agree on invoicing, payment terms, interest on late payments and increases in price (is it a fixed annual increase or an increase linked to the Consumer Price Index?).
- Make sure interest is correctly stated in the contract as per agreement between the parties, i.e. compound, fixed or simple.
- Ensure ALL costs are covered.
- Ensure that the agreement complies with all applicable legislation, e.g. South African Revenue Service (SARS), National Credit Act (NCA), Consumer Protection Act (CPA), etc.
- Penalty clauses for non-performance by the supplier and/or manufacturer.

Table 7.2 presents an overview of the contracting process.

It is, therefore, important to understand the basic rules of the contractual arrangement between the research institution and the supplier/manufacturer before entering into one—the content must be correct and the researcher must be satisfied with the terms and conditions before it is signed. Ultimately a contract is legally binding.

Key to the whole service contract is understanding the difference between the warranty and guarantee of part(s) and/or component(s). A warranty generally refers to an assurance that if the product does not work as is claimed it will be corrected either by repair or replacement of the product within a specific period by the supplier and/or manufacturer void of a refund.

- Many products come with a warranty promising repair or replacement of parts, inclusive of labour, for months, years or life, as defined by the duration of the contract. In theory one can return a product to the supplier for repair but most research equipment suppliers are local distributors of products manufactured elsewhere. It

Table 7.2 Step by step guide to contracting

Step 1	Step 2	Step 3
Set out the contractual purpose, aims and objectives • This should form the basis for the contract preamble • Once the objectives are defined it will determine the contract type and contract name • Consider everything and align with subject matter	Sketch the contract outline; include a list of required and suggested clauses • Look for similar type contracts or precedents for comparison • Make sure there is no company standard • Get feedback from the person who negotiated the contract, compare notes and make sure you are both on the same page	Draft and flesh out the contract; consider each clause • Ensure that each clause fits the contract and won't bite you later • Once again conduct risk assessment, ensure equal balance and fairness • If the agreement is a product of an awarded bid make sure the contract and the accepted bid is aligned

Source Mahlangu (2010)

must, therefore, be ascertained if a faulty product is to be sent to the manufacturer's facility abroad for repair and/or replacement (Mahlangu, 2010).
- An implied warranty is one that arises from the nature of the transaction and the inherent understanding by the buyer rather than from the express representation of the supplier (Mahlangu, 2010).
- The warranty of merchantability is implied, unless expressly disclaimed by name, or the sale is identified with the phrase "as is" or "with all faults" or "Voetstoots". To be "merchantable" the goods must reasonably conform to an ordinary buyer's expectation, i.e. they are what they say they are (Mahlangu, 2010).

A guarantee is a promise assuring that certain conditions will be fulfilled and may or may not have a time limit attached. The original price or consideration paid for the contract will be returned or the product will be replaced (Mahlangu, 2010).

7.7 Summary

The scientific case must justify the need for a specific research equipment. Once such a case has been presented and approved for funding, financial processes and procedures must be employed that adhere to national legislation, which is the PFMA, in South Africa.

The identification of a suitable supplier and/or manufacturer must follow a competitive SCM process. The appointed supplier and/or manufacture must enter into a contractual arrangement either through a service level agreement or a maintenance contract with the research institution. This agreement must be tailored to address training needs, preventative and remedial schedules, time-frames, warranties and guarantees.

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Chapter 8
Conclusion

This book highlights the important role played by RI in advancing science, technology and innovation as well as developing the necessary skills required to operate, manage and maintain research infrastructure across the innovation value chain. The investment across the "Big Five" categories of RI, viz. (i) scientific equipment; (ii) specialised laboratories; (iii) high-end infrastructures; (iv) access to global research infrastructures; and (v) cyber-infrastructure, allows for some of the '*Fundamental or Big Science*' questions to be researched, understood and answered. This includes understanding the global socio-economic and environmental challenges affecting life, such as climate change and carbon emissions, energy resources and security, viral pandemics, food security, biodiversity, global security and economic-interdependencies. These challenges require collaborations in the areas of science, technology and innovation, which involves access to the best RI facilities and expertise in the world. It is important to provide mechanisms that facilitate access and mobility to these GRI, which is necessary for strengthening the development and advancement of research excellence and human capital.

South Africa and the continent at large needs continued and dedicated investment in upgrading, maintaining and replacing research equipment at both specialised facilities and research performing institutions in general. Integrally linked to this investment is dedicated funding directed towards the development of highly skilled workforce.

8.1 Challenges

As a middle-income country, South Africa has made inroads in investing in cutting edge RI platforms. However, there still remains an inequitable distribution or spread of state-of-the-art research equipment across the higher education landscape. This specifically relates to building a strong base of RI including support systems at

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https://doi.org/10.1007/978-3-030-37281-1_8

universities of technologies and rural-based universities that have a minimal infrastructure base especially with regard to well-founded laboratory equipment that forms an essential component of any functional laboratory. Such universities need to have dedicated funding from government for them to be able to level the playing fields in terms of establishing and maintaining a well-equipped and functional RI base.

A second challenge is that of ensuring that there exist parallel investments in human capital development, particularly relating to the training, developing and skilling of the next generation of researchers that can diagnose, maintain and operate RIs independently. This in itself links to the optimal utilisation and sustainability of RIs, given that there currently exists an aging workforce in terms of staff scientists, operators, technicians, engineers and data specialists.

The third challenge lends itself to sourcing the necessary financial resources required to procure, maintain and upgrade research systems. It is here that government, universities, other research performing institutions and industry need to be innovative in the manner in which additional income can be generated. Guidelines for costing usage and access to equipment needs to be set by the institution such that revenue is accrued to either the research department or institution or both, to offset costs related to maintaining equipment.

The fourth challenge extends to the access and usage of research equipment that is available in the country. Funding modalities are required that encourage access to the available research equipment and facilities within the country. This not only boosts usage and publications but also allows for more intensive and longer training for young academics, staff and students at an affordable price compared to having similar activities undertaken at an international facility. Monitoring and evaluating research outputs and human capital development, linked to RI access, is yet another challenge.

Monitoring and Evaluation remains a challenge. Therefore the fifth challenge relates to the incongruencies between the various M&E tools that are utilised at government departments and research performing institutions. It is therefore difficult to fully understand the investment in RI and if this has yielded positive results. The introduction of a singular and robust M&E system that keeps measurable objectives in sight and help monitor progress against high-level objectives and imperatives is a critical enabler for holistically measuring the return on investment in RI platforms.

The sixth challenge relates to the uncoordinated manner in which different government departments and institutions within a country cater for the provision and access to RI platforms. This lack of coherency and structure across the various stakeholders contribute to inefficiencies in managing investments for RI platforms. This, in turn, nurtures pockets of excellence across the already differentiated higher education landscape and any chance of achieving the status of homogeneity is compromised.

The seventh challenge speaks to the building of regional RI capabilities that serve the institutional, regional and national needs in a specific discipline(s), i.e. the research equipment that is supported across various universities despite being geographically located at a single institution. Such a facility requires high access and usage from various types of users based at national and international institutions. The type of research equipment that is required at the regional level usually entails systems that either advances the geographical research priority areas of a specific region or is a type of feeder equipment that is required to prepare samples for the usage of larger more specialised equipment. The latter is what can be deemed specialised equipment that is too expensive to duplicate within any developing or middle-income country. In the case of South Africa, examples of such equipment include the HRTEM at the Nelson Mandela University and the cyclotron based at iThemba LABS.

The final challenge relates to transformation of the researcher cohort that links to gender, age and race—which is a reflection of the historical imbalances of South Africa's apartheid legacy. Interventions and support activities need to be driven that can allow and cater for black and female researchers. In this regard, a mixture of top-down and bottom-up approaches are necessary where government needs to increase its funding towards research capacity, support and other mechanisms to transform previously disadvantaged individuals, academic communities and institutions. On the otherhand, institutions should be more proactive in designing and implimenting interventsions that transform local and national systems. Interventions in this regard will steer the re-sculpturing process towards a more homogenous research landscape.

A summary of the challenges that South Africa faces in sustainably managing RI platforms, is illustrated in Fig. 8.1.

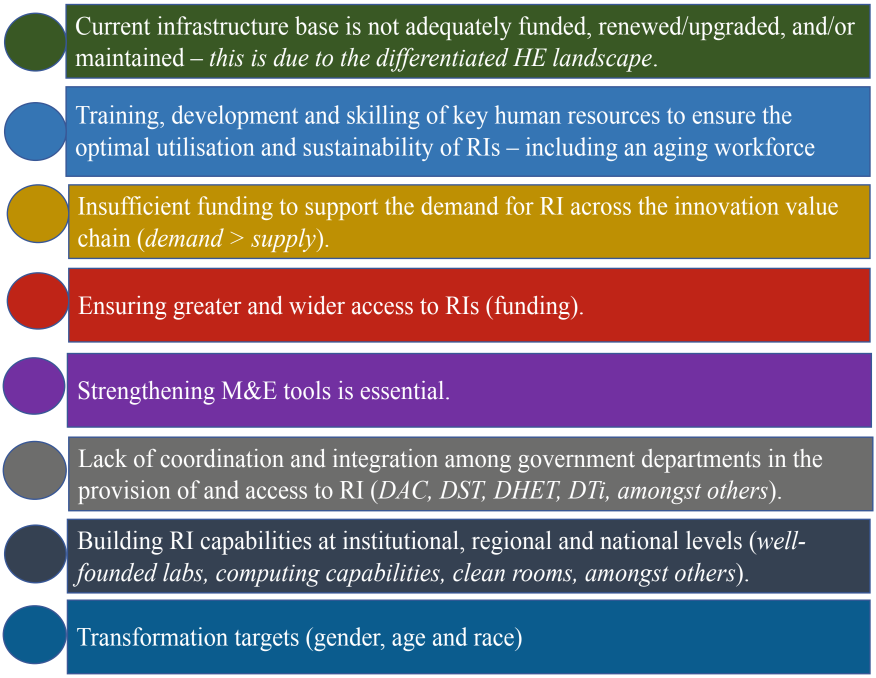

Fig. 8.1 Summary of the challenges associated with the management of research equipment

8.2 Recommendations

Based on the information presented in this book, the following recommendations are proposed as a first step towards addressing some of the challenges outlined above as well as building a well-coordinated research infrastructure system in South Africa and within the continent. The recommendations as provided and listed here do not necessary provide the ultimate solution to each of the challenges listed above. However, they provide a starting point for tackling some, if not most of the challenges, either as a collective or individually, as identified in this book.

Recommendation 1

Parallel investments in human capital development along the innovation value chain, from staff scientists and operators to technicians, engineers and data specialists, must form a core component of the investment in the establishment of RI platforms. Integrally linked to this recommendation is the provision of funding to support (i) research grants; and (ii) mobility and access to RIs. The establishment of a general mobility and access grant, that supports the travel of researchers to RI facilities nationally, continentally and internationally is necessary. Such a mobility grant will ensure that researchers (i) obtain training on how to independently use and manage equipment; (ii) continue to publish in high impact journals that require the usage of the latest technologies; and (iii) graduate students on the basis that new and novel knowledge has been discovered through the use of leading research equipment in the field.

Recommendation 2

An integrated approach across the various stakeholders, spanning government, universities and research performing entities, must be adopted when bidding for RI funding from lead line ministry such as Ministry of Higher Education, Science and Technology, National Treasury or the Ministry of Finance. This ensures that there is a unified and empowered single voice for the infrastructure needs of the researchers within the country. It is this same voice that also motivates for the quantity and type of research equipment required across the innovation value chain.

Expanding on this recommendation is the development of interventions that strengthen synergies across the African continent. This may extend to the (i) establishment of an African agricultural RI facility; or (ii) an African membership to GRIs, such that a cost effective agreement is entered into that provides maximum return to participating African countries. These benefits may include (i) human capital development in areas of scarce skills; (ii) access to world class GRI facilities; (iii) enhancing the research capacities and capabilities of emerging researchers; and (iv) strengthening scientific endeavours to be globally competitive.

Recommendation 3

Given the aging workforce and the skewed workforce in terms of demographics, intensive and directed interventions are needed. These include mentorship and internship programmes that provide hands-on training on the maintenance and operations of state-of-the art equipment. Such interventions have been discussed at length earlier in this book.

Recommendation 4

Sustainability funding is essential for established RI facilities to be able to offer a quality service to the research community, both private and public. Hence it is imperative to plan for RIs across their functional lifespan. Such infrastructure facilities are quintessential for addressing a diverse range of research inquiries. Such facilities need to be maintained and sustained as central analytical facilities and hence need to accrue some revenue based on the nature and type of access by users, without the pressure of becoming a profit-generating entity. If the latter is to transpire, joint funding approaches with industry partners may need to be encouraged that present a lucrative value proposition for usage of public RI platforms. These propositions may include the training of industry staff on the (i) use of research equipment; and the (ii) subsequent analysis and interpretation of the data generated from utilising the equipment. Such value propositions has the potential to accrue to some extent a premium charge-out rate.

Recommendation 5

Monitoring and evaluation (M&E) tools, such as online, real-time databases, are essential for (i) mapping RI investments across the national landscape; (ii) minimising the duplication of RIs in the same institution or region; and (iii) assessing the distribution of specific types of equipment across the country. Other M&E tools include tracking (i) grants expenditures by grant holders; (ii) research productivity of grant holders; and (iii) student training and graduation rates. Penalties must be put in place for non-performance or lack of compliance to the conditions of the grant so as to minimise risk events linked to the management of RI grants by the grant holder and the research institution. M&E tools should also be designed to measure indicators beyond a project life cycle.

A robust online and real-time database can also be utilised to map the spread of RI investments across the African continent with the objective of supporting and strengthening access and collaborations across sister countries on the continent.

Recommendation 6

Identify strategic international partnerships to enhance the joint planning, implementation, budgeting, awarding, and monitoring and evaluating of RI grants. A critical enabler for developing countries is to successfully solicit assistance from developed countries in terms of benchmarking the peer review processes, establishing sustainable research infrastructure platforms, nurturing collaborations and strengthening the quality of research equipment applications.

Recommendation 7

Tailored interventions are needed to meet transformation targets. South Africa has been guided by its Constitution's call to heal the divisions of the past and establish a society based on democratic values, social justice and fundamental human rights. The country has made much progress in these areas since the abolition of apartheid and the realisation of a democratic state. However, such progress has not been able to radically shift the racial and gender profile of the researcher cohort in the country. Radical interventions are required, such as (i) a mentorship programmes between the established researchers who have been successful in obtaining research equipment grants, and historically disadvantaged emerging researchers; and (ii) introducing black and female emerging researchers as co-PIs to the equipment grant application. Such interventions would facilitate the shift in the demographic profile of researchers as well as introduce a feasible succession plan. The subsequent net contribution is that it aids in the development of a feasible sustainable management plan.

Underpinning this recommendation is the focus on social responsibility and outreach. It is paramount that researchers are able to give back to the communities in which they work. This also applies to researchers who are recipients of equipment grants. Community engagement is a very important part of research management and focuses on public awareness as well as the appreciation and engagement of science, engineering, innovation and technology. Outreach activities by research institutions, tend to be aimed at promoting public understanding of science and making informal contributions to science education. It is highly recommended that research institutions host annual outreach programmes that focus on informing school-going learners about the benefits and impact of science on communities. Tours of the facilities housing research equipment can also contribute towards this goal and grow the pool of quality learners that will one day become the scientists and innovators of tomorrow. Some of the outreach activities may include, but not be limited to:

- Public talks or lectures.
- Guided tour programmes for primary and secondary schools.
- Workshops for school teachers and/or students.
- Support science fairs and/or similar events.
- Open day(s) for community members, general public and school learners to access the facility.
- Potential user training with manufacturer and/or supplier involvement.
- Showcase and promote national research infrastructure through social media.

A summary of the recommendations, as described in this section, is outlined in Fig. 8.2.

Fig. 8.2 Summary of the recommendations for managing and awarding RI grants

8.3 Way Forward

The development of world-class infrastructure is a mandatory and necessary prerequisite for realising the successful transformation to a knowledge-based economy and is integrally linked to human capital development.

In a mature system, the best manner in which to consider the allocation of RI investments is informed by a strong scientific case that supports novel research in areas that align to the priority investment areas of the country. If the scientific case has been justified, as deemed by an independent review panel, then the grant allocation from the funding agency should include the following costs:

- Research equipment.
- Feeder equipment and, in most instances, this includes equipment required for sample preparation.
- Research grant for the PI to:
  - Cover operational costs associated with: (i) undertaking their research; and (ii) the management of the equipment, including consumables, running costs and maintenance contracts.
  - Travel nationally and abroad for establishing or nurturing collaborations and conference and/or training attendance.
  - Staff development, postdoctoral training and succession planning support interventions for the development of technical and applications expertise as part of auxiliary training interventions. This specific intervention should solicit matching funding from the research institution.

– Student bursaries for postgraduate students spanning honours to doctoral degrees, inclusive of auxiliary training interventions.

These three components will form not only an ideal RI grant allocation model but also support a holistic approach towards sustainable research infrastructure management.

Annexures

Annexure A: Management Plan Gantt Chart Template

Criterion	Description/explanation	Duration	
		Begin	End
Administration			
• Management of grant funds (management plan, claiming of funds, updating CV, submitting APRs promptly) • Access additional financial resources (as a provisioning tool for currency fluctuations and other ad hoc challenges) • Finalise building or renovation plans • Initiate and complete SCM processes, including tenders • Insurance • Required services and utilities including mandatory safety requirements if needed • Plans to attract other users and encourage access • Financial administration			

(continued)

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https://doi.org/10.1007/978-3-030-37281-1

(continued)

Criterion	Description/explanation	Duration	
		Begin	End
Equipment			
• Testing of the capabilities of similar equipment, ideally from three different suppliers as per grant rules • Identification of the preferred supplier • Final detail specification of the equipment to be procured, designed or upgraded • Manufacturing of the equipment by the supplier • Installation of the equipment • Pre-testing of the equipment • Commissioning and final sign off of the equipment • Acquiring software licences for the equipment at the stage of final sign off of the equipment			
Physical infrastructure			
• Renovate an existing building or construct a new building to house the equipment • Final check and approval of building specifications by supplier technician/engineer • Safety and security measures in place • Alternate energy supply • IT Infrastructure • Other			
Training			
• Appointment of appropriately skilled instrument staff • Succession plan • Training for PI and staff members by supplier • Training workshops for students and other users • Other			

(continued)

(continued)

Criterion	Description/explanation	Duration	
		Begin	End
Maintenance			
• Preventative maintenance schedule defined with supplier of equipment • On-going maintenance and support • Replacement and upgrade of equipment (or its components) • Consumables management • Duration and terms linked to service level agreements and maintenance contracts • Other			
Access		N/A	
• Define an access strategy that facilitates usage of the system which in turn allows for an income generating model to be in place • Costing model for accessing equipment – Researchers from the same institution – Academic Users academic and comprehensive universities as well as universities of technologies – Private Sector • Other		N/A	
Data management			
• Data management strategy, that takes into consideration the following: – Data access policy – Data ethics – Disaster recovery model – Data storage and preservation – Data disposal			

Annexure B: Implementation Framework for Risk Assessment (Kwak & Keheler, 2015)

This provides the guiding principles for the implementation of risk assessments, as described by Kwak and Keheler (2015) with some revisions and modifications. Herewith are a series of questions that can aid funding agency staff with the assessment of risk:

- Is the applying researcher a novice applicant?

- Is the applying researcher and the research institution at which they are employed high risk?
- Is a feasible budget proposed in the application that meets the requirements of the funding instrument? Does this budget make provision for currency fluctuations?
- Does the applying researcher have previous grants from the funding agency?
  - How did the researcher perform as a grant holder (refer to post-grant award phase)?
  - Did the grant holder draw down an excessive portion of the grant?
  - Are there any outstanding grant funds or project activities?
  - Have all required documents and reports been submitted?
  - Was the grant holder on schedule in terms of achieving objectives?
  - Was the grant cancelled or withheld due to non-compliance from the grant holder?
- Does the applying researcher have all necessary documentation attached to the application form?
- As part of the provisioning for awarding a grant the researcher must submit all the necessary supporting documentation prior to the grant being awarded.
- As part of the process for monitoring and evaluation of awarded grants in the post-grant award phase, performance against the following indicators needs to be tracked:
  - Programme-related indicators.
  - Management-related indicators.
  - Financial indicators.

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