SKA OBSERVATORY ESTABLISHMENT AND DELIVERY PLAN
SKA Observatory Establishment and Delivery Plan
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List of Abbreviations

ADP.................................Advanced Data Product
ALMA..............................Atacama Large Millimetre/submillimetre Array
AIV.................................Assembly, Integration and Verification
ASKAP..............................Australian SKA Pathfinder
Az.................................Azimuth
BE.................................Business Enabling
CASS..............................CSIRO Astronomy and Space Science
CBF.................................Correlator-Beamformer
CDR.................................Critical Design Review
CMMS..............................Computerised Maintenance Management System
Co-I.................................Co-Investigator
CP.................................Coordinated Proposal
CPF.................................Central Processing Facility
CPTF...............................Council Preparatory Task Force
CRAF...............................Committee on Radio Frequencies
CSIRO..............................Commonwealth Scientific and Industrial Research Organisation
CSP.................................Central Signal Processor
DDT.................................Director-General’s Discretionary Time
Dec.................................Declination
DG.................................Director-General
El.................................Elevation
EDI.................................Equality, Diversity and Inclusion
EMC.................................Electromagnetic Compatibility
EMI.................................Electromagnetic Interference
EMS.................................Engineering Management System
EOC.................................Engineering Operations Centre
ERP.................................Enterprise Resource Planning
FAQ.................................Frequently-Asked Question
FFT.................................Fast Fourier Transform
FMECA.............................Failure Modes, Effects and Criticality Analysis
FoP.................................Friend of Project
FOV.................................Field of View
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>FPGA</td>
<td>Field-Programmable Gate Array</td>
</tr>
<tr>
<td>FRACAS</td>
<td>Failure Reporting, Analysis and Corrective Action System</td>
</tr>
<tr>
<td>FTE</td>
<td>Full Time Equivalent</td>
</tr>
<tr>
<td>GHQ</td>
<td>Global Headquarters</td>
</tr>
<tr>
<td>GSM</td>
<td>Global Sky Model</td>
</tr>
<tr>
<td>HPC</td>
<td>High-Performance Computing</td>
</tr>
<tr>
<td>HQ</td>
<td>SKA Headquarters</td>
</tr>
<tr>
<td>HoHSSE</td>
<td>Head of Health, Safety, Security and Environment</td>
</tr>
<tr>
<td>HR</td>
<td>Human Resources</td>
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<tr>
<td>HSE</td>
<td>Health, Safety and Environment</td>
</tr>
<tr>
<td>HSSE</td>
<td>Health, Safety, Security and Environment</td>
</tr>
<tr>
<td>IETM/P</td>
<td>Interactive Electronic Technical Manual/Publication</td>
</tr>
<tr>
<td>IGO</td>
<td>Inter-Governmental Organisation</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organisation for Standardisation</td>
</tr>
<tr>
<td>IT</td>
<td>Information Technology</td>
</tr>
<tr>
<td>ITF</td>
<td>Integration Test Facility</td>
</tr>
<tr>
<td>ITU-R</td>
<td>International Telecommunications Union - Radiocommunication</td>
</tr>
<tr>
<td>IUCAF</td>
<td>Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science</td>
</tr>
<tr>
<td>IVOA</td>
<td>International Virtual Observatory Alliance</td>
</tr>
<tr>
<td>JBDC</td>
<td>Jodrell Bank Discovery Centre</td>
</tr>
<tr>
<td>JSP</td>
<td>Joint SKA Proposal</td>
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<tr>
<td>KSP</td>
<td>Key Science Project</td>
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<tr>
<td>LFAA</td>
<td>Low-Frequency Aperture Array</td>
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<tr>
<td>LMC</td>
<td>Local Monitoring and Control</td>
</tr>
<tr>
<td>LRU</td>
<td>Line-Replaceable Unit</td>
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<tr>
<td>LSA</td>
<td>Logistic Support Analysis</td>
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<tr>
<td>LSM</td>
<td>Local Sky Model</td>
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<tr>
<td>LTP</td>
<td>Long-Term Proposal</td>
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<tr>
<td>MCCS</td>
<td>Monitoring, Control and Calibration System</td>
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<td>ODA</td>
<td>Observation Data Archive</td>
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<td>ODP</td>
<td>Observatory Data Product</td>
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<td>OEDP</td>
<td>Observatory Establishment and Delivery Plan</td>
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<tr>
<td>OpsPlan03</td>
<td>SKA Operations Plan Revision 03</td>
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<tr>
<td>Abbreviation</td>
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<tr>
<td>OEM</td>
<td>Original Equipment Manufacturer</td>
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<td>OHS</td>
<td>Occupational Health and Safety</td>
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<td>OLDP</td>
<td>Observation-Level Data Product</td>
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<tr>
<td>OT</td>
<td>Open Time</td>
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<tr>
<td>PA</td>
<td>Product Assurance</td>
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<tr>
<td>PBS</td>
<td>Product Breakdown Structure</td>
</tr>
<tr>
<td>PDF</td>
<td>Portable Document Format</td>
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<tr>
<td>PI</td>
<td>Principal Investigator</td>
</tr>
<tr>
<td>PLDP</td>
<td>Project-Level Data Product</td>
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<tr>
<td>PRTS</td>
<td>Problem Reporting and Tracking System</td>
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<tr>
<td>PSI</td>
<td>Prototype System Integration</td>
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<tr>
<td>PSS</td>
<td>Pulsar Search</td>
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<td>PST</td>
<td>Pulsar Timing</td>
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<td>QA</td>
<td>Quality Assessment</td>
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<tr>
<td>RA</td>
<td>Right Ascension</td>
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<tr>
<td>RAM</td>
<td>Reliability, Availability, Maintainability</td>
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<tr>
<td>RFI</td>
<td>Radio-Frequency Interference</td>
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<tr>
<td>S&amp;TE</td>
<td>Support &amp; Test Equipment</td>
</tr>
<tr>
<td>SARAO</td>
<td>South African Radio Astronomy Observatory</td>
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<tr>
<td>SB</td>
<td>Scheduling Block</td>
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<tr>
<td>SDP</td>
<td>Science Data Processor</td>
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<td>SEAC</td>
<td>Science and Engineering Advisory Committee</td>
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<tr>
<td>SED</td>
<td>Spectral Energy Distribution</td>
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<tr>
<td>SKA</td>
<td>Square Kilometre Array</td>
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<tr>
<td>SKA1</td>
<td>SKA Phase 1</td>
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<tr>
<td>SKA2</td>
<td>SKA Phase 2</td>
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<tr>
<td>SKAO</td>
<td>SKA Observatory</td>
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<tr>
<td>SLA</td>
<td>Service-Level Agreement</td>
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<tr>
<td>SEAC</td>
<td>Science and Engineering Advisory Committee</td>
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<tr>
<td>SLT</td>
<td>Senior Leadership Team</td>
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<tr>
<td>SOC</td>
<td>Science Operations Centre</td>
</tr>
<tr>
<td>SODP</td>
<td>SKA Observatory Development Programme</td>
</tr>
<tr>
<td>SPC</td>
<td>Science Processing Centre</td>
</tr>
<tr>
<td>SRC</td>
<td>SKA Regional Centre</td>
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</tbody>
</table>
SRU..........................Shop Replaceable Unit
SWG..........................Science Working Group
TAC..........................Time Allocation Committee
TAI..........................International Atomic Time
TBD..........................To Be Determined
TM...........................Telescope Manager
ToA..........................Time of Arrival
ToO..........................Target of Opportunity
UK............................United Kingdom
UTC..........................Coordinated Universal Time
VDIF........................VLBI Data Interchange Format
VEX..........................VLBI Experiment
VLBI..........................Very-Long Baseline Interferometry
VO............................Virtual Observatory
XML........................Extensible Markup Language
1 Introduction

1.1 Purpose of the Document

This document is the plan for the establishment and delivery of the SKA Observatory (SKAO). It is a companion to the SKA1 Construction Proposal [RD1]. Together, these two documents lay out all the essential elements necessary to build SKA phase 1 and establish the SKA Observatory as a scientifically productive entity. The plan covers the first decade from the formation of the Observatory as a new international entity and the start of construction, to the first couple of years after the formal completion of the construction program.

This document, the Observatory Establishment and Delivery Plan, describes how the SKA Observatory will operate and the resources required to do so. It identifies all the non-capital costs associated with the Observatory activities. This Plan is structured in three streams of activity – business enabling functions, Observatory operations, and the SKA Observatory Development Program.

The SKA will be operated as a single Observatory, comprising two telescopes – SKA1-LOW and SKA1-MID – operating across three host countries: Australia, South Africa and headquartered in the United Kingdom. The principal purposes of this document are to define: a) how the SKA Observatory will be operated, including the operation of its two telescopes; and b) the resources required.

1.2 Scope of the Document

Staffing and costs for the SKA Observatory are structured into four budget areas:

- **Business enabling** – This includes the Director-General’s Office and corporate governance, human resources, strategy, international relations, finance, IT, communications and outreach, and other enterprise supporting functions. These functions provide essential services to the global organisation as a whole.

- **Observatory operations** – This includes all costs encompassing all functions of the Observatory that are essential for the operation and maintenance of the SKA telescopes, defining and executing the SKA science programme, generating science data products and delivering them to SKA regional centres for release to the community.

- **Observatory development** – This includes all office and non-office costs to develop new techniques and technologies for upgrades to SKA1 or as input to the design of SKA phase 2 (SKA2).

- **Construction support** – This includes all non-capital costs to build, deploy, integrate, verify, and commission the SKA telescopes. This construction support budget complements the capital cost for construction.

This Observatory Establishment and Delivery Plan details the staff identified with all four budget areas listed above. This document provides the description of and justification for the resourcing and costs associated with the business enabling functions, Observatory operations, and the SKA Observatory Development Program but not for construction support activities. The description and justification of the construction support resources and costs are provided, together with the capital costs of construction of SKA1, in the Construction Proposal [RD1].

1.3 Exclusions

This Plan does not address the capital cost of construction of SKA Phase 1, nor does it consider SKA2.

1.4 Verb Convention

The verb **shall** is used whenever a statement is intended to be binding. The verb **will** is used to express an intention. The verbs **should** and **may** express non-mandatory provisions.
2 References

2.1 Applicable Documents

The following documents are applicable to the extent stated herein. In the event of conflict between the contents of the applicable documents and this document, the applicable documents shall take precedence.

[AD1] SKA-TEL-SKO-00001100, SKA1 Construction Proposal
[AD2] SKA-TEL-SKO-0000307, SKA1 Operational Concept Document
[AD3] SKA-TEL-SKO-0000307, SKA1 Operational Concept Document
[AD4] SKA-TEL-SKO-0000122, SKA1 Science Priority Outcomes
[AD5] SKA-TEL-SKO-0000941, Anticipated SKA1 HPC Requirements
[AD6] SKA-TEL-SKO-0000951, Anticipated SKA1 Archive Requirements
[AD7] SKA-TEL-SKO-0000116, SKA1 External VLBI ICD
[AD8] SKA-TEL-SKO-0000102, SKA RAM Allocation
[AD9] SKA-TEL-SKO-0000103, SKA Support Concept
[AD13] MIL-STD-1388-2B, Department of Defence Requirements for a Logistic Support Analysis Record
[AD19] SKA-TEL-SKO-0001083, SKA Computing Hardware Risk Mitigation Plan
[AD20] SKA-TEL-SKO-0000315, Science Commissioning and Verification Plan, Rev01
[AD21] SKA-TEL-SKO-0000735, SKA Regional Centre Requirements, Rev03
[AD22] SKA-TEL-SKO-0001640, Calibration Plan
[AD23] SKA-TEL-SKO-0000937, Global and National Networks for SKA Science, Rev02
[AD24] SKA Regional Centres Steering Committee, White Paper, Rev01
[AD25] SKA-TEL-AIV-4410001, Roll-out plan for SKA1-LOW, Rev09
[AD26] SKA-TEL-AIV-4410001, Roll-out plan for SKA1-MID, Rev09
3 Organisational Structure

The Organisational Design for the SKA Observatory has been adopted in this Plan, and that for the initial implementation is shown in the figure below. The design does not directly affect the overall resourcing or costs and will likely continue to evolve somewhat to most effectively support construction and operation of SKA1.

![Organisational Structure Diagram](image)

**Figure 1. The organisational design for the SKA Observatory used in this plan.**

3.1 Executive Group and Senior Leadership Team

The SKAO executive group will be the primary internal forum advising the Director-General on strategy and decision making for the Observatory as a whole. This executive group comprises:

- Director-General;
- Programme Director (currently also deputy DG);
- Director of Operations;
- Head of the DG’s Office;
- Science Director;
- Head of HR;
- Chief Finance Officer;
- Head of Assurance;
- SKA-LOW Telescope Director; and
- SKA-MID Telescope Director.
The executive group will meet regularly in order to fulfil those purposes and will likely meet face-to-face once or twice a year.

The executive group will be complemented by a larger and more inclusive senior leadership team (SLT), comprising the leads of each major group. Their purpose is to provide and discuss business function and activity across the Observatory, primarily, facilitating internal communication and coordination, discussing issues related to the management of the Observatory, and providing broad input to decision making and the work of the executive group. The SLT is intentionally large, reflecting an inclusive approach to management, especially during the period covered by this plan when both construction and operations activities are underway. The size of the group reflects the complexity of this period of establishment of the IGO with around 14 partners, undertaking activities on three continents, with the necessity for a wide knowledge of key issues and challenges. The SLT will meet periodically for purposes of communication and information exchange. Almost all SLT meetings will likely be virtual (rather than face-to-face).

The senior leadership team of the SKA Observatory will comprise:

- Director-General;
- Programme Director (currently also deputy DG);
- Director of Operations;
- Science Director;
- Head of HR;
- Chief Finance Officer;
- Head of Assurance;
- Head of the DG’s Office;
- SKA-LOW Telescope Director;
- SKA-MID Telescope Director;
- Head of Strategy;
- Head of International Relations;
- Head of Secretariat;
- Director of Communications, Education and Outreach;
- SKA-LOW Site Construction Director;
- SKA-MID Site Construction Director;
- SKA-LOW Telescope Deputy Director; and
- SKA-MID Telescope Deputy Director.

The makeup of these leadership teams is a decision of the Director-General and will necessarily reflect his or her personal preference.

The SKAO will be a partnership of member countries on five continents, hundreds of staff, and thousands of scientific users from across the world. This multi-cultural, global science collaboration is by nature diverse, and its diversity is a source of strength for the Observatory. Equality and diversity are enshrined in the SKA convention and we are proud that these values appear in the founding document of the Observatory, committing us to an organisation in which they are promoted and respected. The SKAO is committed to equality, diversity, and inclusion in its leadership and at all levels through the Observatory, encompassing gender balance, nationality, and representation of traditionally underrepresented groups. SKAO’s Equality, Diversity and Inclusion (EDI) Policy will be underpinned by an associated EDI strategy developed in conjunction with an EDI working group of staff charged to identify and drive actions to support the delivery of the Observatory’s equality vision and will form an integral part of the broader People Strategy, as referenced in point 1 of section 5.3.1.
4 Governance

The governance structures for the SKA Observatory are under development and will be implemented following entry into force of the SKA convention and the creation of the SKA Observatory as an intergovernmental organisation. The governance structures and processes are important drivers of the planning of elements of the Observatory organisational structure, especially in some of the business enabling functions. The key governance committees and working groups along with the connections to the SKA Observatory Council are shown in the figure below.

Figure 2. Governance and advisory committees anticipated for the SKA Observatory.

The Finance Committee reports directly to the SKA Observatory Council and will have quite a broad remit. In addition to overseeing all financial issues, it will have sub-committees that will oversee general administrative and legal issues, procurement and tendering processes, the delivery and oversight of in-kind deliverables for the construction project.

The Science and Engineering Advisory Committee (SEAC) will be the principal technical advisory committee to Council. Its membership will have a broad range of scientific, engineering, and technical expertise, including computing and software development, and will provide broad advice to Council and to the DG regarding scientific priorities and emerging technical developments and opportunities.

The time allocation committee will be responsible for the assessment of all scientific proposals to use the SKA, ranking the proposals according to scientific merit and recommending the science program to the Director-General. The users’ committee will provide feedback to the Director-General on the perspective of the scientific users of the Observatory regarding the performance of the telescopes and delivery of the science program.

The SKA Observatory Council will likely adopt a mechanism whereby less formal “committee of Council” meetings are convened to explore and discuss issues (but not for formal Council decisions). The Council is also expected to establish ad hoc working groups and advisory panels from time to time.

Other governance and advisory mechanisms anticipated for both construction and operations activities are described in the companion SKA Construction Proposal, and later sections in this plan.
5 Business Enabling

The role of business enabling (BE) functions is to provide services to support the entire range of SKA activities, spanning transition, construction, and operations. The functions are core services common to many organisations and comprise:

- Director-General’s Office;
- finance, procurement and facilities;
- human resources;
- information technology;
- assurance, HSSE and spectrum management.

As the SKA Observatory will be a standalone legal entity, these functions will provide a centralised pool of professional expertise that act as key business partners to the Observatory as a whole.

The location of the BE functions in the Observatory structure is indicated in the figure below where they are identified in orange.

![Diagram of the organisational design for the SKA Observatory used in this plan.](image)

Figure 3. The business enabling functions, shown in orange in the organisational design for the SKA Observatory used in this plan.

A degree of overlap of some BE roles, especially in the communications, education, and outreach team (within the DG’s Office), and of BE roles in the telescope host countries, will be implemented and a team approach to the delivery of BE functions will be strongly encouraged. This approach will help avoid the creation of silos between different BE functions and minimise the risk posed by single-point failures in staffing.
This structure will be implemented in late 2020, somewhat in advance of the transition of the SKA from a UK-registered company, the SKA Organisation, to the intergovernmental organisation (IGO) – the SKA Observatory. More detail of the transition to the IGO and other activities specific to the first year of this Plan are presented in the 2021 Business Plan [RD27].

5.1 The Director-General’s Office

5.1.1 Scope

The DG’s Office will be the executive arm of the Observatory. At the time of writing, its functions are delivered through separate teams, working closely together but split across several departments within the SKA organisation. As identified from an earlier study and external advice on the optimum organisational structure, these critical strategic, relationship, communications, and policy-focused functions will move into a single team to strengthen the coordination of and coherence across such activities and directly support the Director-General. Evolution into the structure described below will take place in Q3/Q4 2020, ready for the establishment of the Observatory and the transition from the SKA organisation, which will take place as early as practicable in 2021.

The Council is the governing body of the Observatory and will set the overall policy and direction of the SKA Observatory. The DG is the chief executive of the Observatory with the responsibility of overseeing the construction and scientific programme of the SKA, under the direction of the Council.

The DG’s Office will be the core function supporting the DG’s activities with regards to the delivery of the Observatory’s mission. The Office will have responsibility for the formulation of strategic and operational planning initiatives that require endorsement by the Council (or a Council committee) and will act as the link between the various elements of the Observatory’s activities to ensure coherence of mission. It will be responsible for governance activities that ensure the Observatory is meeting its legal and strategic commitments, be the focus for the relationship with the Observatory’s governance structure, ensure a sustained, targeted and meaningful engagement with stakeholders, and will act as the secretariat for all Observatory governing bodies.

The DG’s Office will deliver a broad range of functions summarised below.

- The Secretariat will provide corporate governance support including:
  - executive assistance to the DG and leadership team;
  - governance and secretariat support to the SKA Council and the full suite of advisory bodies to Council, including the planned finance committee, science/engineering committee(s) and other relevant bodies; and
  - administrative services will provide general administrative support for cross-Observatory activities.

- The Legal Counsel will support consideration of international and domestic law matters including:
  - Working with a range of external advisory bodies, providing expert advice and guidance to SKA leadership and governance bodies in the interpretation and implementation of international and local legal requirements to ensure compliance.
  - Providing legal guidance and services across a wide range of matters related to business-as-usual running of the Observatory, including agreements, contract management, employment and human resources, trademarks and intellectual property considerations.
Facilitating the legal implementation and supporting operation of the Observatory in the UK, in the telescope hosting countries, and around the Observatory partnership.

- **Strategy** will oversee the establishment of the SKA as an international organisation and support delivery of its mission through:
  - Leading the implementation of the Observatory post-transition activities and transformation plan establishing a fit-for-purpose international organisation poised for delivery of the mission.
  - Developing, together with the stakeholder base, and then maintaining, a strategic vision and medium/long-term plans for the Observatory and its activities, coherent with the founding plans for SKA1 construction and operation, along with specific delivery plans for that vision, for approval by the Council.
  - Supporting the DG and working alongside the international relations team in strategic matters, including negotiations on funding and future membership.
  - Working with governing bodies and the secretariat and as the internal coordinating function, to prepare key policy, strategic programmatic (for example procurement) financial and related matters for resolution.
  - Designing and executing future business change and organisational development.

- **International relations** will provide the primary international stakeholder relations function by:
  - Ensuring effective engagement with members (as defined in the convention [AD8]), host countries, prospective members and others to ensure that strategic perspectives are reflected in the Observatory’s plans.
  - Strategically targeting activities to ensure that the mission and objectives of the Observatory, and particularly the construction of SKA1, can be realised through delivery of sufficient resources.
  - Ensuring visibility of SKA within an international (national, regional, and global) context and other forums with the aim of delivering on the Observatory’s strategic vision and plans.
  - Providing support for the effective day-to-day functioning of the Observatory across the membership, and in particular, with the host countries.
  - Working in the broader DG’s Office to ensure that the compelling opportunities for broader societal and non-scientific impact from the Observatory are encouraged, enabled and tracked.

- **Communications, outreach and education** will assist the DG in ensuring the growth of financial, political and public support for the SKA Observatory and its programmes by:
  - Growing and safeguarding the brand of the Observatory internationally.
  - Raising awareness of the Observatory’s vision, mission and values; its scientific objectives, progress and impact with key stakeholders.
  - Consolidating the SKA communications network in member and prospective member countries to ensure continued alignment with the Observatory’s vision, mission and values, and optimising coordination.
  - Making the most of online channels (websites, social media, blogs, etc.), emerging technologies and trends to maximise the reach and impact of the Observatory’s programmes with key audiences.
  - Ensuring regular and positive engagement with key stakeholders at a local, national and international level through targeted programmes, campaigns, and initiatives; paying particular attention to the needs of communities near the telescope sites in close coordination with our local partners.
- Maintaining a coherent and sustained internal communication effort (in close coordination with HR and senior SKA leaders) across SKA Observatory sites and departments to ensure staff alignment with the Observatory's vision, mission and values, awareness of the Observatory's key developments and progress, and suitable avenues for two-way communication.

The organisational structure of the DG’s Office is given in the figure below.

![Organisational Structure of DG’s Office](image)

**Figure 4. The internal structure of the DG’s Office.**

The DG’s Office will manage relations with all partner countries, with particular attention paid to the three SKA host countries. In the case of each host country, two structures are envisaged. For the UK, as specified in the HQ host agreement, a joint consultative committee with members from the UK Government departments (FCO, BEIS and STFC), and the University of Manchester (as host of the SKA global headquarters) will be led by the DG’s Office (through the strategy team with assistance from legal counsel). This joint consultative committee will deal with most of the practical matters related to the HQ host relationship. In addition, SKAO will establish a forum for bilateral ‘programmatic’ dialogue forum with the UK as a Council member (primarily through the international relations team). Equivalent structures are envisaged with each of the telescope host countries, Australia and South Africa.

**5.1.2 The Directorate**

**5.1.2.1 Purpose and Key Stakeholders**

The DG is the principal contact and is ultimately responsible for all activities undertaken by the Observatory. The DG’s Office is the executive arm of the Observatory and the Head of the DG’s Office will support the DG in the management of all interactions with the SKA Observatory Council as well as assisting them in delivering the Observatory’s mission.

**5.1.2.2 Roles and Resources**

A short description of each role within the directorate at global headquarters (GHQ) is given in Table 1.
Table 1: Role descriptions and staff required to support the directorate function of the SKA Observatory.

<table>
<thead>
<tr>
<th>The Directorate</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
</table>
| Director-General (DG)                                | GHQ      | The DG acts as the Chief Executive Officer for the SKA Observatory and as its legal representative and is appointed by and reports to Council. The DG shall:  
• Exercise project, operational and financial authority as provided by the Council.  
• Submit a strategic plan, and plans for the long-term, medium-term and annual activities of the Observatory to Council.  
• Submit an annual report to the Council.  
• Submit budget estimates to the Council.  
• Submit audited annual accounts to the Council.  
• Attend Council meetings in a consultative capacity.  
• Be responsible for general management of SKAO.  
• Be accountable for health and safety.  
• Perform all other duties as delegated by the Council. | 1       |
| Deputy Director-General                              | GHQ      | The Deputy DG role is not a distinct position but is filled by a nominated member of the senior leadership team (currently the Programme Director). The purpose of this designation is primarily to identify the member of the leadership team who assumes the acting DG role when the DG is not available. |        |
| Head of Director-General’s Office                     | GHQ      | The Head of the DG’s Office is a strategic leader reporting directly to the DG. This role works closely with the DG to provide advice and support in all matters relating to the delivery of the mission of the Observatory. In shaping the strategic direction for SKA this role will be highly visible, interacting with the SKA communities and with the Council and its advisory bodies. The Head of the DG’s Office also assists the DG in promoting the Observatory globally, driving effective engagement and relationships with governments, members, prospective members, partners and other organisations. Horizon scanning and the ability to take account of emerging external and political issues is key to this. Within SKA this role leads the delivery of a diverse set of functions. | 1       |
5.1.3 The Secretariat

5.1.3.1 Purpose and Key Stakeholders

The secretariat function covers the range of corporate governance and administrative support required for the SKA Observatory and has relationships with a wide range of internal and external stakeholders. This function comprises a Head of Secretariat and roles to provide executive assistance to the DG, as well as governance and secretarial support to the Council and its advisory bodies. General administration services also sit within this function.

5.1.3.2 Delivery Plan

In the current SKA organisation era, there are two parallel streams of governance and governance preparation activities. The SKA organisation Board of Directors is the governing body and is supported by a small secretariat function through the Head of Administration. The Board Secretariat works closely with the legal team to facilitate day-to-day governance activity. In parallel, the work to prepare for the implementation of the SKA Observatory is undertaken by the Council preparatory task force (CPTF).

This team will not substantially change in the Observatory era described in this plan. The resources currently in place in the SKA Organisation that support the SKA Board and its various committees will continue to operate in a broadly similar fashion once the transition to the SKA Observatory is complete. During 2021 and 2022 there will be a period when both the SKA Board of Directors and the SKA Observatory Council will coexist. Supporting the Council will be a family of subcommittees including a finance committee and an evolution of the current Science and Engineering Advisory Committee (SEAC). In turn, the draft committee structure design identifies further sub- and advisory committees (for example policy advisory committees and subcommittees of the finance committee), all to be supported by the secretariat.

5.1.3.3 Roles and Resources

A short description of each role within the secretariat at GHQ is given in Table 2.
Table 2: Role descriptions and staff required to support the secretariat function of the SKA Observatory.

<table>
<thead>
<tr>
<th>The Secretariat</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
</table>
| Head of Secretariat              | GHQ      | The Head of Secretariat is responsible for a range of governance activity. This role works closely with the DG, Chair of Council and Head of DG’s Office to ensure the work programme for the SKA Council and its advisory bodies is delivered.
   This role will also be responsible for managing all aspects of protocol related to international partners, and for maintaining the archives and records of the SKA Observatory. | 1      |
| Senior Secretariat Administrator | GHQ      | Provides secretariat functions to the Council and its advisory bodies.       | 1      |
| Junior Secretariat Administrator | GHQ      | This role supports the Head of Secretariat in managing the work programme and providing secretariat duties for Council and its advisory bodies. | 1      |
| Executive Assistant             | GHQ      | The Executive Assistant will provide support to the DG, Deputy DG, and Senior Directors including diary and meeting management; and will line manage the administrative services department. | 1      |
| Administrative Officer          | GHQ      | This role provides general administrative services and support to the DG’s Office and across the organisation. | 1      |
| Receptionist(s) (0.5 FTE)       | GHQ      | This role provides receptionist services at SKA HQ. This role is focussed on the day-to-day management of visitors and provides a range of support for events and meetings. | 2      |

The Executive Assistant will also serve as Head of the administrative services group. This small group will comprise of the administrative assistants who report to their division or department lead for day-to-day activities; they have a dotted-line reporting connection to the Executive Assistant.

5.1.4 Legal Counsel

5.1.4.1 Purpose and Key Stakeholders

The Legal team will initially comprise a legal counsel and a deputy/associate, both based at the SKA Observatory HQ. As the Observatory presence in the two telescope hosting countries is established, they will be joined by in-country (IGO) staff in South Africa and Australia. The specific allocation of responsibilities and the role titles of these additional staff will be refined as the model for the delivery of these functions in the telescope host countries is developed further.

The legal team will be responsible for all matters associated with the operation of the Observatory as a legal entity with an international personality. The team will work to support all contractual and legal matters needed to enable the Observatory to function, engaging external counsel as and when required. Examples of issues to be supported include human resources and workplace relations, employment contracts, procurement, support for the programme team in establishing legal agreements with contractors, and other business-as-usual matters. Externally, the team will be responsible for establishing and implementing the legal personality of the SKA Observatory as a ‘new

1The Head of Secretariat will continue to support the SKA Board and its advisory bodies while the SKA organisation remains a legal entity. As company secretary to the SKA organisation the Head of Secretariat will also manage company closure activities.
international organisation’ across three primary domains in the UK, South Africa, and Australia, but also more broadly across the membership. Delivery of a coherent programme of privileges and immunities as described in the Observatory convention has already been highlighted as a significant challenge, and ‘steady-state’ operation may not settle for some considerable time. The legal team will be at the forefront of negotiations and discussions with government stakeholders from the member countries and frequently at the interface of the programme and strategy areas.

5.1.4.2 Delivery Plan

The legal team will be the first point of contact for expert advice and guidance on all international and domestic legal matters for the Observatory. Led by the legal counsel, the team will:

- Provide legal guidance and services across matters related to business-as-usual running of the organisation, including agreements, contract management, employment contracts and trademarks and intellectual property considerations.
- Lead on implementation and day-to-day operation of the legal requirements of the convention, privileges and immunities protocol, host country agreements and operating partnership arrangements.
- Support procurement in all legal aspects of construction and operations contract preparation and management.
- Liaise with external legal counsel and other IGOs on shared best practice.
- Advise on international law and support international court and tribunal activity.

5.1.4.3 Roles and Resources

A short description of each role within the legal counsel team at GHQ is given in Table 3.

Table 3: Role descriptions and staff required to support the legal counsel function of the SKA Observatory.

<table>
<thead>
<tr>
<th>Legal Counsel</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legal Counsel</td>
<td>GHQ</td>
<td>Legal Counsel reports to the Head of the DG’s Office and is an experienced legal practitioner with detailed knowledge of international treaty law and other law related to the governance and operation of the Observatory. This role advises senior management to ensure the SKA Observatory complies with all relevant international and domestic laws.</td>
<td>1</td>
</tr>
<tr>
<td>Assistant Legal Counsel</td>
<td>GHQ</td>
<td>The Assistant Legal Counsel reports to legal counsel and provides a range of legal services including, but not limited to, employment contracts, commercial support and contract management, legal agreements, treaty law and inter-governmental organisation rules.</td>
<td>1</td>
</tr>
</tbody>
</table>

5.1.5 Strategy

5.1.5.1 Purpose and Key Stakeholders

The strategy team will be the base for strategic planning and coordination of planning activities.

Strategic planning and support for an effective international organisation lie at the heart of the DG’s Office function. The SKA organisation strategy team has for some time been heavily focused on the work to design and establish the SKA Observatory as an inter-governmental organisation, coordinating
an intricate process to develop the founding documents and policies, and then translate them, through the process of transition, into the new inter-governmental organisation. The creation of the DG’s Office, bringing together the functions of governance support, external relations, legal and communications, aims to enable an effective coordination mechanism in support of the DG in their leadership of the Observatory.

The strategy team will interact with key stakeholders both internal to the Observatory (essentially all Observatory groups) and externally (primarily the members and their representatives on Council). Internally, the goal will be to ensure programmatic and policy coherence, employing best practice business change management processes to ensure implementation of effective policies. While, externally, acting as a direct support mechanism for the Council and the DG, preparing policy positions and papers, alongside the International relations team and others to prepare the ground on issues.

The strategy team will play a coordinating role to ensure that there is alignment across the Observatory and that decisions support the business of the SKAO. This team’s role includes the development of the Observatory’s strategic plan that must provide a coherent top-level outline for the Observatory’s activities and progress. The strategy team will also ensure that policy changes are tested against all relevant business areas to ensure that the impacts are understood before implementation decisions are taken. Such activities will involve an interface to the communications, education, and outreach team which will drive internal communications to ensure effective awareness and understanding of such issues within the broad Observatory staff.

5.1.5.2 Delivery Plan

In the initial period of the Observatory’s lifetime, there will be a significant task of embedding the structure of the post-transition organisation. In the HR and finance spaces, and especially in governance, evolution will continue to create a new steady-state organisational structure. This structure and the direction of the Observatory will be governed by a new Council which will work to an overall strategy that will need to be defined within this team.

The first goal of the team will be to oversee the establishment of the SKA Observatory as a functional inter-governmental organisation across the three host countries and other member countries, as detailed in Section 5.1.1.

5.1.5.3 Roles and Resources

A short description of each role within the strategy group at GHQ is given in Table 4.
Table 4: Role descriptions and staff required to support the strategy function of the SKA Observatory.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head of Strategy</td>
<td>GHQ</td>
<td>The Head of Strategy reports to the Head of the DG’s Office and provides advice and support across a wide range of areas. Working with the DG, directors, and a range of external stakeholders this role develops and maintains the strategic plan ensuring that the vision, mission, and objectives of the SKA Observatory are met. The Head of Strategy also works closely with the Council and external advisory bodies to address the key policy, strategic and financial matters for resolution. Develops and manages strategic relationships with members, governments, partners, and other organisations to ensure collaboration, continuous improvement, sharing of best practice, and the co-ordination of long-term Observatory planning. This role also leads a change management function for the Observatory.</td>
<td>1</td>
</tr>
<tr>
<td>Strategy Support Officer</td>
<td>GHQ</td>
<td>The Strategy Support Officer reports to the Head of Strategy and provides change management support. Working closely with a range of stakeholders, this role coordinates all aspects of the varied and complex programme of work to ensure implementation of the SKA Observatory into a fully functioning organisation and to support business readiness and implementation of organisational change.</td>
<td>1</td>
</tr>
<tr>
<td>Strategy Support Advisor</td>
<td>GHQ</td>
<td>The Strategy Support Advisor reports to the Head of Strategy and provides a range of support services to the strategy team. This includes the preparation and management of artefacts for both internal and external stakeholders as well as specific product development support.</td>
<td>1</td>
</tr>
<tr>
<td>Strategy Admin</td>
<td>GHQ</td>
<td>Provides administrative support to the Head of Strategy.</td>
<td>1</td>
</tr>
</tbody>
</table>

5.1.6 International Relations

5.1.6.1 *Purpose and Key Stakeholders*

Integral to the DG’s Office is the need to ensure an ability to develop and maintain effective external (international) stakeholder relationships. Working closely with the co-located strategy and communication functions in the DG’s Office, the intention is to enable a structure where strong relationships can be maintained with the formative Observatory membership, and that new and effective strategic relationships can be built which will lead to new members/associate members (as defined in the convention [AD8]) of the Observatory. The work of the team will be guided by a strategy, to be developed once the Observatory has been formed, which will set out the primary aims of fulfilling the convention’s objective of enabling a ‘global collaboration in radio astronomy’ but modulated by a clear operational requirement in the nearer term of enabling the strongest possible financial contribution to the Observatory to enable construction and operation of the SKA1 design baseline instrument.
5.1.6.2 Delivery Plan

The near-term focus for the team is to support the establishment and early days of the Observatory’s function. The transitional years of 2021 and 2022 will be dominated by the challenges of ensuring that the momentum of membership built up in the last years of the SKA organisation can be maintained into the Observatory. The membership transition from the organisation to Observatory for some countries will be potentially complex, and the focus of the team (as part of the broader DG’s Office) will be to support negotiations, ‘business case development’, and legal mechanisms enabling prospective new members, associate members or cooperating partners to associate with the Observatory. Bespoke tactical approaches will be needed for each, encompassing scientific case building, industry/programmatic discussions and legal considerations.

The experience from the CPTF era (and the organisation) shows the necessity of careful and significant effort being deployed to support discussions with prospective stakeholders, with effort focused in the most beneficial areas. Learning from the experience of other organisations, dedicated effort will be directed to each of the Observatory members with at least annual face-to-face engagement and commitment to supporting action around industry days, community events and similar. Particular focus will be on the three hosting countries, and an appropriate balance, guided by Council discussion, struck between existing and ‘new’ members.

Aside from member state relationships, the other prime area for activity is in support of the Observatory’s relationship with entities such as the European Union (EU) and its organs, the United Nations (UN), G7, and other bodies.

A critical area of work throughout the plan period is the establishment of a function to monitor the impact of the Observatory and its activities. In the organisation era, the strategy and communications teams have engaged in various initiatives to plan for effective monitoring of the broader societal impact of SKA as a global research infrastructure. SKA has a potentially unique opportunity to establish methodologies for such monitoring at the point of establishment of the Observatory, and then follow them through the lifetime of the organisation. Such work will be increasingly important in the requirement for establishing SKA as a sustainably resourced infrastructure. The international relations team will lead this effort.

5.1.6.3 Roles and Resources

A short description of each role within the international relations team at GHQ is given in Table 5.
Table 5: Role descriptions and staff required to support the international relations function of the SKA Observatory.

<table>
<thead>
<tr>
<th>International Relations</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head of International Relations</td>
<td>GHQ</td>
<td>This role reports to Head of the DG’s Office and works closely with them to provide the stakeholder relations function dealing with members, host countries, prospective members and other actors by: • ensuring engagement and managing relations with members, host countries, prospective members and others; • monitoring the evolution of the organisation's international partners and prospect member states and provide the Head of DG’s Office with appropriate information and recommended actions; • assisting the Head of DG’s Office in identifying objectives for SKAs engagement with other international organisations and institutions; • supporting the Head of DG’s Office in all the activities connected with the coordination of SKA’s participation in relevant forums; and • ensuring visibility of SKA within an international context and other forums.</td>
<td>1</td>
</tr>
<tr>
<td>International Relations Officer</td>
<td>GHQ</td>
<td>This role reports to the Head of International Relations and works closely with them and the Head of DG’s Office to support the stakeholder relations function across the membership. Between the team members and within the DG’s Office, there will be a systematic approach to covering all elements of the member relations. In addition, one specific objective for this role is to deal with relations between SKA and the other intergovernmental entities such as peer infrastructure organisations, the UN, the EU, and similar bodies, and to centrally manage all EU related matters, including advice on R&amp;D funding opportunities.</td>
<td>1</td>
</tr>
</tbody>
</table>

5.1.7 Communications, Outreach, and Education

5.1.7.1 Purpose and Key Stakeholders

The communications, outreach and education function (hereafter called “communications”) is responsible for upholding and positioning the SKA brand and in growing the public, political (and ultimately financial) support for the SKA Observatory and its programmes. It provides strategic direction for communications activities across the partnership and oversees all aspects of communications at SKA HQ, as well as providing resources to deliver effective, bespoke, targeted, and timely communications, outreach and education across the Observatory and its stakeholders.

The communications function is responsible for disseminating information to a wide variety of stakeholders to build and maintain support for public investment in the Observatory by highlighting its positive contributions to society, whether they are scientific, technological or societal.

The remit of the communications team covers:
• brand custodianship;
• media relations;
• corporate and science communication;
• online communication and social media;
• content production;
• risk and crisis communication;
• internal communication; and
• organisation of special events, exhibits, outreach, and education.

Within the DG’s Office, the communications function will work closely with the international relations team to deliver efficient and effective coordination with member and prospective member countries, to support in-country lobbying activities and to leverage opportunities across the partnership. This ensures that the global communications strategy and SKA-country communications strategies are aligned and complementary, and leverages opportunities across the partnership, ensuring that the global communications strategy and SKA-country communications strategies are aligned and complementary.

The key audiences for SKA Communications are:

• decision-makers – government ministers, senators, prime ministers, international body leaders and their offices;
• key influencers – senior officials, diplomats, key industrial sectors, and chief scientists;
• interest groups – scientists, engineers, industry groups, lobbyists, local communities around telescopes sites;
• multipliers – journalists (TV, press, radio), social media influencers, celebrities, science communicators, and teachers;
• general audiences – the general public, voters, and school children; and
• staff and associates – Staff working for SKAO and its partner organisations, and associates involved in SKA activities.

5.1.7.2 Delivery Plan

The SKA communications function owns the Observatory’s communications strategy, which has evolved to support the organisation’s objectives to retain current member countries and attract new ones, support activities across the partnership, grow further international awareness of the project as a major international scientific endeavour and its ambitious scientific goals, and support the transition and further develop the SKA brand. These efforts have contributed to SKA’s high visibility and its positioning in the landscape of large-scale research infrastructures.

The remit of the communications team is broad, ranging from strategic communication, brand custodianship, corporate communication, internal communication, risk & crisis communication, stakeholder engagement to content development, online communication, science communication, public outreach, media relations, public affairs, and education.

The year 2021 will mark the start of a significant expansion of SKA communication activities, extending into the telescope host countries and adding the development of curriculum-based educational materials and support for radio astronomy outreach.
Key components for this strategy to be successful are:

- high-level institutional support and adequate level of resources;
- high visibility of the communications function within the Observatory;
- effective integration of the function at the core of SKA business and policies;
- a seamless interaction with the strategy and international relations functions within the DG’s Office and more generally other Observatory functions;
- integrated communications function across the three SKA Observatory sites; and
- effective collaboration with communications teams at partner institutions, ensuring sharing of intelligence and in-house communications resources and skills.

As the SKA evolves from pre-construction to construction and to early scientific operations, the communications team will progressively ramp up to cover an increasingly wide range of expertise necessary to deliver an efficient and world-class communications programme. The team will adopt a mixed delivery model, with some skills available in-house either within the SKA Observatory or at partner institutions willing to make them available to the partnership, while other skills will be outsourced. Outsourcing of activities to third parties including partner institute communications staff will also be considered as and when needed.

Complementing the SKA communications team at HQ, the staff in each of the telescope host countries will cover branding monitoring and promotion at the local level, national and local stakeholder engagement, media interaction, VIP (and other) visits to the sites, national/local events, local outreach, a public visitor programme, as well as science communication activities (continued coverage of pathfinder and precursor science and later, SKA early science) for all relevant platforms and audiences. These resources are planned and budgeted within telescope operations.

5.1.7.3 Roles and Resources

A short description of each role within the communications team at SKA HQ is given in Table 6. These staff are complemented by three communications and outreach roles (two nominally at the SOC and one at the EOC) working within each of the SKA1-LOW and SKA1-MID operations teams in Australia and South Africa, respectively. The in-country communications and outreach staff will report to the respective SKA1 Telescope Director; they will have a strong dotted-line reporting relationship with the communications team at SKA HQ.

Table 6: Role descriptions and staff required to support the communications, outreach, and education function of the SKA Observatory.

<table>
<thead>
<tr>
<th>Communications, Outreach and Education</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Director of Communications</td>
<td>GHQ</td>
<td>Provides the strategic direction for communications, outreach, and education across the entire partnership and oversees all aspects of communications, both internal and external. Assists the DG in ensuring high visibility of the SKA Observatory and positioning of the SKA brand in high political spheres and in growing the financial, political, and public support for the Observatory by communicating its value to stakeholders and the general public. Ensures efficient and effective coordination with member and prospective member countries. Chairs the communications steering</td>
<td>1</td>
</tr>
</tbody>
</table>
### Communications and Outreach Manager

**GHQ**

Supports the Head of Communications in the development and implementation of the SKA global communication and outreach strategy. Undertakes all the expected activities of a communication and outreach department of any major scientific project and ensures quality delivery, focused on the particular SKA context. This includes overseeing online communication for the SKA via the website and other multimedia platforms, representing the SKA at public forums such as conferences and on relevant committees, liaising with a diverse range of stakeholders from different backgrounds at local, national and international levels, media relations, public outreach and development of promotional materials. This role chairs the outreach network, comprised of outreach professionals across the SKA partnership and beyond, promoting coordination of projects, mutualising resources and lobbying for the SKA in countries.

### Online Community and Content Officer

**GHQ**

The Lead Producer of original content for the SKA, including but not limited to writing content for webpages and newsletters, blog posts and drafting press releases. Contributes to other material such as scripts, interviews, factsheets, and brochures. This role runs the SKA’s official social media channels, creating and publishing engaging posts and associated content.

### Events Management Lead

**GHQ**

In charge of the organisation, management and logistics of events and medium to large meetings at the SKA HQ. Ensures the efficient and effective delivery of meetings at the SKA HQ and international conferences organised by the SKA at venues around the world.

### Outreach and Events Officer

**GHQ**

Supports the communications, outreach, and education team with specific, one-off projects and events, and with general day-to-day operations. This includes content production, design and development of promotional and exhibition material. Assists with setting up/dismantling displays and stands, and with outreach events locally and abroad.

### Press Officer

**GHQ**

Run the SKA’s engagement with media worldwide. They proactively develop and maintain an international network of journalists, pitch relevant stories to the media to maximise visibility of key project milestones, manage media requests and interviews, and support SKAO staff through media training. Press officers will also coordinate media events, press conferences and visits at the SKA sites.
5.2 Finance

5.2.1 Scope

The Finance function includes procurement and facilities and has responsibilities spanning financial management and reporting, procurement policy and its implementation, and facilities which comprise the management of the SKA HQ building at Jodrell Bank.

The finance team is responsible for all financial and commercial matters at both strategic and operational levels, including those as follows:

- Strategic financial advice and council level representation on all financial matters. The finance team will lead the development of long-term financial plans, annual budgets, cost-benefit analysis, and other financial modelling as required. The Chief Finance Officer will have line management responsibility for team members and will act as a key channel to the Council, the finance committee and for other Observatory-level interactions.

- Design, control, implementation, and monitoring of internal processes to ensure that the Observatory is managed in a sound financial manner. In particular, policies and procedures are required to ensure a strong treasury function for the management of working capital and foreign exchange risk, as well as for broader finance topics such as forecasting and re-basing of budgets using escalation of income and costs. This function must provide the in-country telescope operations teams with the ability to conduct business autonomously, doing so within Observatory-wide systems and controls provided from an HQ-based group finance function.

- Oversight of the recording of all financial transactions, both cash and in-kind. This includes the processing of all accounts and financial transactions. The culmination of this activity is the production of financial statements that are compliant with IPSAS (International Public Sector Accounting Standards) which will be the Observatory’s primary record of financial activity. In
addition, the finance team will be responsible to ensure all financial and taxation regulatory requirements are met. This includes but is not limited to obtaining refunds of VAT/GST and other indirect taxes in multiple jurisdictions, calculation and accounting for internal taxation schemes applicable to staff granted privileges and immunities, filing of tax statements and declarations, payment and reconciliation of staff deductions for tax and pensions (likely in at least three countries), and the lodgement of statistics returns as may be required.

- Asset records management. The Observatory will acquire a significant number of high-value assets during the construction phases. Some of these will be assets that represent the aggregation of a number of work tasks and procurements to deliver a single asset such as a functioning antenna. Working closely with the assurance team, careful planning will be required to develop asset management system(s) that are appropriate for a number of disparate uses including maintenance engineering, custody of assets, insurance, and financial reporting.

- Budgeting and management reporting. The master budget will be developed and approved by the Council in accordance with the financial rules and regulations. The budget will be developed in close consultation with the senior leadership team and heads of BE functions to ensure plans are complete, accurate, and consistent. Once approved, devolved budget responsibility will be managed within the ERP system and multi-currency plans will be produced to allow the Telescope Directors to manage and report in their local currency.

- Development and maintenance of an enterprise resource planning (ERP) system.

- Management of cash and currency reserves. In simple terms, this will involve ensuring the Observatory maintains liquidity and manages the significant risk of multiple large currency exposures.

The procurement team will establish procurement procedures and processes for the new inter-governmental organisation and ensure that goods, services, and works are procured in full compliance with SKA’s policy, rules, and procedures. These will also be in accordance with the basic principles of best value for money, fairness, transparency, and effective competition, to meet the relevant quality, schedule, and technical requirements of the Observatory.

The procurement team will also provide an Observatory-wide logistics function. Careful consideration must be given to all transactions involving the movement of goods internationally. Logistics specialists within the team will develop an overarching strategy to support timely and cost-efficient mechanisms for the handling of goods and services. In particular, they will support the observatory in areas of freight, insurance, movement of hazardous goods, customs clearance, export controls, VAT, duty, and excise exemptions.

The facilities team will deliver both strategic planning and day-to-day operations in relation to buildings and premises at SKA HQ. It covers setting up of security control, coordination of building maintenance, upgrades, relocations, and the management of outsourced services providers. Facilities staff also work closely with the overall Jodrell Bank site owner, Manchester University.
5.2.2 Financial management and reporting

5.2.2.1 Purpose and Key Stakeholders

The finance function will primarily support the DG to establish financial plans, processes, and systems to ensure sound financial management and operation of the Observatory. Its direct stakeholders include:

- SKAO Council and Finance Committee – strategic financial planning and reporting;
- Observatory members;
- SKAO Senior Leadership Team and Managers – financial management and control;
- Auditors and regulatory bodies – compliance with taxation, accounting standards, etc.;
- Commercial suppliers and customers of the Observatory; and
- SKAO staff, secondees, visitors and affiliates.

5.2.2.2 Delivery Plan

A priority will be the development of the finance module within the Unit4 ERP product. ERP development and implementation activities are overseen by an internal ERP steering committee comprising business-function owners and key user groups within SKAO. The Observatory is building its business processes around the ERP in support of, but not as a substitute for, roles for experienced managers in all three host countries that are included in the staffing plan.

In 2019 SKA successfully implemented Unit4 Business World as its ERP (enterprise resource planning) capability and the system is to be expanded to meet the requirements of the Observatory and will have the following features:

- the primary resource to record and maintain budgets in a hierarchical fashion to allow accurate information to be provided at any level of the Observatory;
- maintenance of budget data to reconcile with council approved plans;
- interface and exchange of data to and from project and contract management systems;
- ability to record transactions (budgets/actuals) in the local currency of each host sites;
- consolidation to provide a single Observatory view of the master budget and financial performance in the nominated reporting currency (EUR);
- electronic workflows to provide effective financial control;
- functionality that allows free flow of appropriate data to end-users as and when they need it;
- online processing of all financial transactions with minimal use of paper-based transactions; and
- real-time accurate data to assist in cash and currency forecasting.

A core finance process is the ‘purchase to pay’ value chain. The business processes of the SKA Observatory will be geared towards a ‘self-serve’ approach supported by the finance team which will provide expertise in specialist areas such as budgeting, treasury, and strategic financial advice, in addition to monitoring compliance with transaction-level processes.

Expenses for low-value items and travel will generally be incurred and processed using corporate credit cards issued widely to SKA staff. For higher value items, traditional purchase orders will be raised with the assistance of the procurement team to ensure appropriate oversight and compliance with the policy.

A significant and essential ERP task is the ongoing maintenance of core data tables, managing regular updates and releases, security and role profiles of users, development of reports and implementation
of new and enhanced functionality. In addition, a significant effort is required in the role of ‘system accountant’. This role performs all the necessary set up of data tables to house discreet data sets for budgets/actuals by financial year and ensure that data is reconciled and archived appropriately at the end of fiscal years. They also ensure system integrity of staff, supplier, customer and other key static data. Final details of the design are dependent on the nature of operations with SKA’s delivery partners in telescope host countries.

Testing of ERP developments is an integral part of the ERP implementation which is overseen by an internal ERP steering committee. Appropriate staff time for testing will be allocated by business function owners and users.

The management of cash flow and currency risk is mission-critical. This will be managed centrally within SKA HQ by staff with appropriate specialised experience and expertise.

The HQ-based finance team will work in an integrated fashion with finance and administration staff based in the telescope host countries. Some functions will be retained at HQ to maintain effective internal control, such as oversight of bank accounts and credit card approvals. HQ staff will be responsible for the development and roll-out of policies, procedures, training to allow the telescope host country staff to operate semi-autonomously. Host countries will manage a local instance of the general ledger for in-country finance activities in the local currency, and HQ staff will then present consolidated accounts for the SKA Observatory.

5.2.2.3 Roles and Resources

A short description of each role within the finance team at SKA HQ is given in Table 7. These staff are complemented by three roles in each of the SKA1-LOW and SKA1-MID operations teams in Australia and South Africa, respectively. These are currently envisaged as a Finance Officer, a procurement officer, and a Legal and Contracts Officer though the specific allocation of responsibilities and the role titles are subject to change as the model for the delivery of these functions in the telescope host countries is developed further. In-country finance staff will report to the relevant SKA1 Telescope Director but will also have a strong dotted-line reporting relationship with the finance team at SKA HQ.
Table 7: Role descriptions and staff required to support the finance function of the SKA Observatory.

<table>
<thead>
<tr>
<th>Finance</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chief Finance Officer</td>
<td>GHQ</td>
<td>Lead the finance, procurement, and facilities function and provide a range of financial advice and insights to assist the Observatory in meeting its goals.</td>
<td>1</td>
</tr>
<tr>
<td>Finance Manager</td>
<td>GHQ</td>
<td>Responsible for management of all operational financial activity.</td>
<td>1</td>
</tr>
<tr>
<td>Treasury Manager</td>
<td>GHQ</td>
<td>Manage cash flow and currency exposures.</td>
<td>1</td>
</tr>
<tr>
<td>Group Financial Accountant</td>
<td>GHQ</td>
<td>Consolidation of accounts from sub-ledgers and ensuring accuracy and consistent accounting across the HQ and host country finance teams.</td>
<td>1</td>
</tr>
<tr>
<td>ERP Manager</td>
<td>GHQ</td>
<td>Oversee both operational and strategic development of ERP system.</td>
<td>1</td>
</tr>
<tr>
<td>ERP Analyst</td>
<td>GHQ</td>
<td>Testing and support of the ERP system.</td>
<td>1</td>
</tr>
<tr>
<td>Management Accountant</td>
<td>GHQ</td>
<td>Prepare and maintain all budgets, forecast and management reports for SKAO departments.</td>
<td>1</td>
</tr>
<tr>
<td>Finance Assistant</td>
<td>GHQ</td>
<td>Processing and data entry support for all finance group activity.</td>
<td>2</td>
</tr>
</tbody>
</table>

5.2.3 Procurement

5.2.3.1 Purpose and Key Stakeholders

The procurement team will lead the procurement of mission-critical construction and engineering contracts from established international supplier markets, through engaging with SKA’s internal stakeholders and international partner institutions. It will provide an end-to-end procurement service using insights based on market knowledge to help develop attractive and professional tender documents and ensure that suppliers are interested and engaged throughout the procurement process. Relevant stakeholders include SKA project and budget managers, the SKA industrial liaison network (comprising the industrial liaison representative nominated by each member country), and the wider supplier network that will interact with the Observatory.

5.2.3.2 Delivery Plan

During the construction phase, significant activity will be required to assist the work package project teams. Prior to the commencement of SKA1 construction, the Observatory will recruit several contract and procurement specialists. This process has commenced in 2020 and will continue into 2021. The number of contracts specialists required is a direct function of the number of significant contracts to be procured and it is estimated that there are approximately 60 significant contracts to be procured over 3 years. The work package teams have significant resources to develop the necessary technical and engineering specifications and provide an evaluation of supplier responses throughout the purchasing process. The work package project teams will contribute specialist expertise in support of the procurement activities in the form of project managers, system engineers, and domain experts.

The current projection for cash vs in-kind procurement for the construction of SKA Phase 1 is a 75/25 split by work package budget. In-kind procurements will be managed through NEC4 in a way that closely parallels the management of cash procurements. The programmes team resourcing plan has taken careful account of the implications of managing in-kind procurements, and this will be monitored and adjusted if necessary.
The role of procurement will be to ensure that other requirements are met, including:

- systems are in place to ensure efficient flow of information to prospective suppliers, evaluation panels, and other stakeholders;
- levels of probity and confidentiality consistent with SKA policies are maintained throughout the procurement lifecycle;
- information to prospective suppliers is comprehensive and covers technical, commercial, site-specific, HSE and any other relevant requirements; and
- ongoing contract management services.

### Roles and Resources

A short description of each role within the procurement team at SKA HQ is given in Table 8. These staff are complemented by three roles in each of the SKA1-LOW and SKA1-MID operations teams in Australia and South Africa, respectively. These are currently envisaged as a Finance Officer, a Procurement Officer, and a Legal and Contracts Officer though the specific allocation of responsibilities and the role titles are subject to change. The in-country procurement staff will report to the relevant SKA1 Telescope Director but will have a strong dotted-line reporting relationship with the procurement team at SKA HQ.

Table 8: Role descriptions and staff required to support the Procurement function of the SKA Observatory.

<table>
<thead>
<tr>
<th>Procurement</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Procurement Services</td>
<td>GHQ</td>
<td>To establish and lead the procurement function for SKAO.</td>
<td>1</td>
</tr>
<tr>
<td>Senior Contracts Specialist</td>
<td>GHQ</td>
<td>The contracts specialist works closely with senior internal stakeholders to ensure the timely procurement of complex contracts to an agreed plan. The contracts specialist is responsible for leading the timely procurement of mission-critical construction and engineering contracts from established international supplier markets.</td>
<td>5</td>
</tr>
<tr>
<td>Contract Specialist</td>
<td>GHQ</td>
<td>The procurement category specialist works closely with senior internal stakeholders to ensure the timely procurement of engineering and construction contracts to an agreed plan.</td>
<td>3</td>
</tr>
<tr>
<td>Buyer</td>
<td>GHQ</td>
<td>Junior position – procures contracts of a lower complexity, value and/or risk.</td>
<td>1</td>
</tr>
<tr>
<td>Logistics Specialist</td>
<td>GHQ</td>
<td>Ensures that goods are shipped internationally and arrive safely and on time at destination – responsibilities are management of shipping contract, tracking of shipments, management of clearing and customs formalities and expediting.</td>
<td>1.5</td>
</tr>
</tbody>
</table>
5.2.4 Facilities

5.2.4.1 Purpose and Key Stakeholders

The facilities team ensure that all staff and visitors to SKA HQ are provided with a secure, safe and amenable working environment\(^2\). In addition, this team will be responsible for significant coordination with Manchester University, the owners of the Jodrell Bank UNESCO designated site and the landlord for the SKA HQ building.

5.2.4.2 Delivery Plan

This small team will continue to manage SKA HQ, interacting extensively with all the teams working in the building to ensure that the services meet their needs and to facilitate effective forward planning. The team manages external contractors as required and works closely with the facilities function of the University of Manchester and its Jodrell Bank site.

5.2.4.3 Roles and Resources

A short description of each role within the facilities team at GHQ is given in Table 9.

Table 9: Role descriptions and staff required to support the facilities function of the SKA GHQ.

<table>
<thead>
<tr>
<th>Facilities Manager</th>
<th>GHQ</th>
<th>Responsible for both strategic planning and day-to-day operations in relation to buildings and premises, setting up of control, monitoring and reporting processes and the management of outsourced services providers.</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilities Support</td>
<td>GHQ</td>
<td>Ensures that the global SKA HQ building and surrounding premises is kept safe and clean in compliance with best practice.</td>
<td>0.85</td>
</tr>
</tbody>
</table>

5.3 Human Resources

5.3.1 Scope

People are integral to the success of the Observatory and the human resources (HR) function is responsible for all people-related practices at both a strategic and operational level, including those as follows.

1. Defining and delivering a people strategy that meets the needs of the Observatory through:

   - The development and implementation of strategies that allow the Observatory to attract and retain the international and diverse talent it needs through a progressive recruitment and attraction strategy;
   - An employee value proposition that defines our approach to development, reward & benefits, and policy; and
   - An equality, diversity, and inclusion strategy that enables us to develop a diverse workforce where all staff are valued, underpinned by a culture of respect and inclusion.

\(^2\) The equivalent function in Australia and South Africa will likely be delivered by a combination of CSIRO/SARAO staff and SKA Operations staff. An informal linkage to Facilities staff at HQ may be of some benefit.
2. Delivering an end-to-end service in relation to the effective employment, engagement and management of all staff through:

- The management of all recruitment and selection activity through to offer, onboarding, induction and where applicable relocation, as well as the management of secondee arrangements;
- Dealing with issues at work, including the management of absence, and working closely with HSSE on the health and wellbeing of our staff;
- Management of the staff forum/staff consultative body;
- The management of the annual pay review process in line with our reward strategy; and
- The development and maintenance of the HR part of the ERP system, supporting and enabling the development of management information and effective HR administration across all processes, including working with finance and payroll to ensure staff are correctly paid.

3. Building organisational and leadership capability, both externally through the recruitment of skilled individuals, and through performance and development to ensure the Observatory has the skills it needs to be successful in the future. HR will do this through:

- the development of a strategic workforce plan, reviewed and updated annually, identifying the roles, employment types and critical capabilities needed in the future;
- the management of performance and development, ensuring training resources are focused on the development of the critical skills needed for the future, including the development of leadership and management capability;
- talent and succession management ensuring risks are identified and talent developed to mitigate against these risks, whilst enabling career development and retention for our most able staff; and
- the management of job families and associated career framework supporting associated performance management, development, and staff progression.

4. Developing efficient and effective people practices which value the needs of staff, balancing these needs with those of the organisation whilst being aligned to the Observatory values through:

- the development and maintenance of policy, procedures, supporting guidance and documentation, across multiple jurisdictions – noting the requirement for certain differences for staff covered by P&I versus those not in each employed location; and
- conducting periodic staff engagement surveys to inform and influence our HR and employee relations strategy.

SKAO HR will be directly responsible for HR activities related to employees of the SKAO. As the employer of many of the operations staff in the telescope host countries, CSIRO and SARAO will be responsible for their own staff. However, the SKAO HR team will maintain open and active communications with HR staff in CSIRO and SARAO to facilitate the exchange of information and ensure awareness on both sides in each telescope host country, especially in planned activities that could have an impact on the operations staff.
5.3.2 Purpose and Key Stakeholders

The purpose of the HR function is two-fold:

1) To enable the success of the Observatory through ensuring we can attract, engage and retain the right staff and resources we need in the right locations, equipped with the necessary skills, experiences and capabilities to deliver the goals of the project.

2) To support the DG and senior leadership team to deliver a high performing culture characterised by effective leadership and supported by an HR approach that enables delivery of the business plan, whilst minimising and mitigating staff-related risks and ensuring legal compliance.

Direct stakeholders include:

- SKA Observatory Council and HR-related governing bodies (in relation to remuneration, staff rules and regulations);
- Observatory members;
- senior leadership team and managers;
- staff Association or equivalent;
- SKA Observatory employees, secondees and other external resources such as contractors; and
- members of partner organisations we work with for the delivery of our human capital objectives. This will include representatives from SARAO, CSIRO and supplier organisations.

5.3.3 Delivery Plan

The HR delivery plan is underpinned by our Equality, Diversity and Inclusion strategy, which is at the heart of everything HR does, with a particular focus on:

- leadership – building and supporting inclusive leadership capability, where leaders and managers lead by example, are alert to and committed to removing bias and actively valuing and benefiting from a diversity of perspectives and experiences;
- recruitment – attracting and recruiting diverse talent;
- policies and procedures – developing and implementing policies which allow SKAO to attract, engage and retain a broad diversity of staff, underpinned by equality and inclusion; and
- culture and values – creating and nurturing a culture that values difference, engenders inclusion, and creates an environment where everyone can be at their best.

The principle of “invent once and replicate” will be adopted in the way the HR team works. This will avoid unnecessary duplication of activity across host countries and will maximise uniformity across the Observatory to the extent possible, consistent with the “one Observatory, two telescopes, three host countries” ethos.

The intention is that recruitment will be conducted in house, as opposed to using recruitment agencies or otherwise outsourcing recruitment activities, which is a significantly more expensive option. A substantial recruitment effort is required in order to deliver this plan successfully. Close monitoring of recruitment progress will continue during the ramp-up of SKAO staffing, and in the event of delays relative to the plan, resources will be added to the HR team.

The HR team will be supported by an enterprise resource planning (ERP) system, and HR staff are contributing to the design and implementation of SKA’s ERP platform, Unit4 Business World. More detail is given under the finance section above.
SKAO’s HR policies and procedures are being developed to enable the most efficient way of employing and managing staff, with simplicity at its heart. Where policies become overly complex, the impact of these on the resources needed to manage them will be reviewed.

There will be staff in the SKA Observatory who are subject to different jurisdictions with the intention that the local HR staff in each location will provide the local employment knowledge where needed. There will be HR staff in Australia and South Africa who are SKA Observatory employees, these roles being at a senior HR advisor level. These individuals will take strategic and operational direction from the HR team at HQ in the UK; they will have the skills to operate without close local HR supervision.

HR will support and provide a service to a diverse and international staff base. Many positions will be recruited internationally, and many new staff will relocate to take up their appointment in one of the host countries. A driving principle of HR planning is to afford a similar level of support to SKA Observatory employees regardless of their location.

A mix of employment contract types is envisaged, but indefinite contracts are expected to dominate rather than fixed-term contracts. SKAO will aim to balance the mix of indefinite and fixed-term contracts to match the requirements of the roles, maximise the attractiveness of SKA as an employer of choice, and facilitate a degree of staff turnover and renewal. A strategic workforce plan will set out the detail and timing of future roles and critical capabilities that are required and identify the proposed contract type. It should be noted that a high proportion of SKA roles require technical expertise and capabilities that are scarce in the external employment market. Being able to attract and retain diversity and highly specialised skills the Observatory needs will be key to its success.

The annual strategic workforce plan will be developed by the Head of HR, based on input from division heads, which will be costed jointly with the CFO. The DG will present the plan to the Council as part of the annual budgeting and planning process.

The HR team will work closely with the Observatory senior leadership team to encourage any staff association that is formed to adopt a light-touch approach, rather than operating with the high process levels adopted by staff associations in other IGOs. Regular and frequent interaction with staff representatives, and investment by all senior SKA leaders to actively engage in order to build and maintain the necessary trust and confidence, will be key to achieving this outcome.

As referenced earlier, the SKA Observatory will be resourced through a combination of staff employed by SKAO and those employed by CSIRO and SARAO. Close collaboration with representatives from these partner organisations will be key to ensuring the Observatory, CSIRO, and SARAO are able to recruit the best candidates for SKA roles in the most efficient, effective, and consistent way.

The figure below summarises how this collaborative approach will work, underpinned by a tri-partite group made up of HR recruitment representatives across SKAO, CSIRO, and SARAO. This group will meet regularly to ensure:

- common understanding of planning and progress against the recruitment plan;
- the most efficient, effective and consistent way of working, sharing learning and coordinating approach for maximum impact;
- coherent messaging to ensure a positive and coordinated approach to the management of the SKA brand;
transparency and management of candidate expectations throughout the recruitment process, to support ongoing future Project engagement; and
maintenance of recruitment standards, encouraging consistency across different locations where applicable.

A Collaborative Recruitment Approach

<table>
<thead>
<tr>
<th>UK Based</th>
<th>Partner Location (Aus/ZA)</th>
<th>SKAO/Partner Collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKAO Managed</td>
<td>Low: Local Advice and guidance</td>
<td>High: Multiple roles across host countries</td>
</tr>
<tr>
<td>SKAO Employed</td>
<td>Medium: Single roles</td>
<td>SKAO/Partner Collaboration</td>
</tr>
<tr>
<td>Partner Employed</td>
<td>Partner Employed</td>
<td>SKAO/Partner Collaboration</td>
</tr>
</tbody>
</table>

- SKAO advertise and manage selection to offer
- Supported by SKAO ATS System
- Recruitment standards developed against defined roles requirements
- Local HR Assistance
  - Attraction
  - Selection
  - Offer
  - Query handling

- Recruitment including approvals, selection through to offer management by partner organisation
- Attraction and advertising by partner. May vary if roles across multiple locations, promoted through SKA Project recruitment campaigns
- Recruitment standards agreed against defined roles requirements
- SKAO representation on the recruitment panel

Figure 5. The collaborative approach to recruitment by the SKAO, CSIRO, and SARAO.

5.3.4 Roles and Resources

A short description of each role within the human resources team at SKA HQ is given in Table 10. These staff are complemented by one HR advisor working within each of the SKA1-LOW and SKA1-MID operations teams in Australia and South Africa, respectively. The specific allocation of responsibilities and the role titles are subject to change as the model for the delivery of these functions in the telescope host countries is developed further. Those in-country HR staff will report to the relevant SKA1 Telescope Director but will have a strong dotted-line reporting relationship with the human resources team at SKA HQ.
Table 10: Role descriptions and staff required to support the HR function of the SKA Observatory.

<table>
<thead>
<tr>
<th>Human Resources</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head of Human Resources</td>
<td>GHQ</td>
<td>Responsible for leading the HR function, developing and implementing an HR strategy that supports the Observatory’s strategic objectives, and leading the HR team to provide a comprehensive HR service to staff and management across all aspects of the employee lifecycle. Responsible for ensuring the developing of SKA’s people practices which value the needs of staff, balancing these needs with those of the organisation whilst being aligned to the Observatory values.</td>
<td>1</td>
</tr>
<tr>
<td>HR Administrator</td>
<td>GHQ</td>
<td>Assists in providing an effective and up to date HR service, across all aspect of the HR lifecycle, to the employees and management through the administration of all HR processes and the production of reports and management information.</td>
<td>2</td>
</tr>
<tr>
<td>HR Advisor</td>
<td>GHQ</td>
<td>Works with the HR project managers and the broader HR team in providing an effective and up-to-date HR service.</td>
<td>1</td>
</tr>
<tr>
<td>HR Project Manager (resourcing and Org Capability)</td>
<td>GHQ</td>
<td>Works closely with the Head of HR in building organisational and leadership capability, both externally through the recruitment of skilled individuals, and through performance and development to ensure the Observatory has the skills it needs. Leads the management and implementation of the HR recruitment, resourcing and capability plan to ensure the organisation is appropriately resourced and equipped with people with the right skills, capabilities and frameworks to meet the current and future IGO needs, whilst reflecting the international nature of the project. Also responsible for the management of the strategic workforce plan, performance and capability development activity, leadership development, talent management, development and coaching.</td>
<td>1</td>
</tr>
<tr>
<td>HR Project Manager (policy, reward and engagement)</td>
<td>GHQ</td>
<td>Works closely with the Head of HR in the development and maintenance of the Observatory’s people practices and policies. Develops and maintains all supporting procedures and guidance notes, working closely with the HR advisors in all countries to provide oversight on the development, maintenance, and application of the local procedures and guidance to support effective delivery of the policies. Manages the implementation of the employee value proposition, including reward &amp; benefits and policy. Manages employee relations, co-ordinating staff association interactions and providing expert guidance on any associated employee relations matters.</td>
<td>1</td>
</tr>
</tbody>
</table>
5.4 Information Technology

5.4.1 Scope

The information technology (IT) function maintains the core information and communication technologies for the Observatory that supports all its business functions (scientific data systems are out of the scope of this function; they are managed through the construction and Observatory operations teams). The IT team supports the Observatory through managing collaboration and sharing technologies, and developing services and technologies such as video conferencing, mobile working, Cloud platforms and identity and access management. It ensures the security of SKAO business data and systems.

5.4.2 Purpose and Key Stakeholders

The information technology team provides a holistic service covering areas including end-user computing, IT systems operations, network and security, communications, applications management, service management, and governance.

Stakeholders are not limited to staff but include an extensive pool of collaborators, contractors, visiting experts, and members of the executive bodies and committees; all of whom are provided identities and a support service as appropriate.

The IT team secures and protect stakeholders and data using a range of methods and tools including prevention, detection, and alerting. The team provides secure and appropriately scalable environments, both internally and in Public Cloud. This enables the hosting and supporting of core infrastructure collaboration and messaging, scientific operations, software development activities and development of large data storage, processing and retention. However, the scope does not include support and processing of science data products themselves.

5.4.3 Delivery Plan

The IT team at SKA HQ will not ramp up substantially in size following the transition, though it will be augmented by staff in the telescope host countries. Support is currently provided to stakeholders distributed internationally across multiple time zones by staff at HQ in the UK adopting an extended working day. New resources in the telescope host countries will allow for a follow-the-Sun approach, providing support to users over a greater fraction of the 24-hour day. Resiliency and redundancy will be built into the IT systems to maximise reliability. We do not anticipate the need to provide full 24/7 support for business-related IT services, though critical issues that arise out of working hours for any IT staff will be escalated as appropriate. If necessary, an on-call rota system may be implemented through this is not included in the current plans.

The core IT support team comprises support analysts which are generic roles. Cross-training and an ongoing program of skill development and formal training are a key feature of the IT delivery plan. The IT support roles in telescope host countries will also be integrated with those based at HQ to provide a more robust and cohesive support team. More specialist senior roles cover the critical skills needed and provide a path for promotion and development. A recent decision to recruit a specialist with capability in IT networking and security will result in additional capability in this area.

Automation will be used to improve efficiency and reduce manual effort on the completion of repetitive tasks and progress has already been made to reduce repetitive tasks undertaken by the team and to improve event management.
The IT team issue computing equipment to all SKAO staff, generally comprising a laptop, mobile/cell phone, and peripherals. Laptops are centrally managed and joined to the internal directory service (ADDS) facilitating compliance with IT policies. Network access control will be implemented following the separation of the SKAO from the University of Manchester IT network (late 2020) allowing only SKAO devices to access core HQ networks and systems. IT maintains a standard device list and is moving to a role-based approach for decisions regarding hardware and software allocation, and identity and access management, to better control costs and security. IT manages the full asset lifecycle through procurement, records management (AMDB, CMDB, Capital Investment Plan), build, control, maintenance, refresh, and disposal.

Commensurate with the small scale of the team, and the modest scale of the Observatory staff complement, all proposals to implement Observatory-wide supported software will continue to receive very close scrutiny and be subject to the IT and wider software and computing approvals processes. Strategic decisions to acquire the software tools required for the business will be made on an Observatory-wide basis and will consider the costs and risks of support. A similar effort will also be made to identify and retire legacy software.

The IT roles based in the telescope host countries will generally be more junior than those at HQ and will be focused on day-day support activities. These roles will be line managed through local telescope operations teams with strategic oversight from the IT team based at HQ. As noted above, in-country staff will supplement the core service management team, allowing for extended support hours and providing cover for any temporary loss of headcount in the support team at HQ. IT staff from the telescope operating partner organisations CSIRO and SARAO may also be sourced from time to time to provide additional support.

Additional resources may be contracted from external expert organisations for defined and time-limited activities such as consultancies or external assurance such as security assessments. Additionally, resources from the wider software & computing team can provide support and guidance if individual specialities and experience would benefit any initiative. Equally, the wider project will be supported by expertise within IT.

Role-based controls will be developed to determine application access, distribution list membership, hardware assignments, and data access. These controls will be heavily automated taking feeds from other sources, such as HR systems. A focus on identity and access management development will ensure the existing large stakeholder user base (already 1000+) is better managed and the controls will be able to scale up to support the predicted increase in stakeholders as the Observatory moves towards operation.

IT costs are managed through procurement controls, application portfolio and licence management, asset lifecycle management, and Cloud operations monitoring and optimisation. Further, software licence compliance is achieved through established software asset management techniques, both manual and automated. An approvals process ensures new software purchases are properly vetted and their use, including their storage of data, support the requirements of the future Observatory.

5.4.4 Roles and Resources

A short description of each role within the IT team at SKA HQ is given in Table 11. These staff are complemented by three IT support staff at the SOC and two at the EOC working within each of the SKA1-LOW and SKA1-MID operations teams in Australia and South Africa, respectively. The in-country IT staff will report to the relevant SKA1 Telescope Director and will have a strong dotted-line reporting connection to the IT team at SKA HQ.
Table 11: Role descriptions and staff required to support the IT function of the SKA Observatory.

<table>
<thead>
<tr>
<th>IT</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head of IT</td>
<td>GHQ</td>
<td>Develop and implement the IT strategy and lead the IT team in the delivery of the associated service provision, including the management of suppliers and associated tenders/procurement activities. Responsible for the delivery of the IT strategy, consistent with the Observatory’s IT policy.</td>
<td>1</td>
</tr>
<tr>
<td>IT Operations Specialist</td>
<td>GHQ</td>
<td>Design, implement, maintain, and continuously improve IT systems and Cloud platforms. Act as a point of technical escalation. Lead on major technical projects and to support in the creation of operational process and procedures.</td>
<td>1</td>
</tr>
<tr>
<td>IT Network &amp; Security Engineer</td>
<td>GHQ</td>
<td>Implement and maintain network and security technologies. Manage, prevent, or mitigate security incidents and cyber-attacks. Create an identity and access management regime supporting all stakeholders’ access to systems as dictated by role.</td>
<td>1</td>
</tr>
<tr>
<td>IT Support Analyst</td>
<td>GHQ</td>
<td>Ensure the provision of fit-for-purpose information technology to enable all staff to deliver the Observatory’s objectives. This will include support for all IT hardware and software, collaboration and communication tools, meeting and video conferencing systems and the development of support, reference and knowledge materials. Ensure continuity of service through maintenance and backup and recovery of all systems.</td>
<td>3</td>
</tr>
<tr>
<td>Internship(s)</td>
<td>GHQ</td>
<td>Internships will be used to support the IT activities, supplementing the IT support analysts.</td>
<td></td>
</tr>
</tbody>
</table>

5.5 Assurance

5.5.1 Scope

The assurance function is focussed internally, assuring the DG that all processes and procedures are aligned with quality, HSSE (Health, Safety, Security and Environment), spectrum management, corporate responsibility, and other standards mandated by policy. The assurance function is also responsible for the management of Observatory (corporate) risk and supports policy development. Assurance is also responsible for insurance, which is an important element of risk mitigation.

Product and quality assurance for the construction project, whilst integrated into programmes for day-to-activities, reports to the Head of Assurance in order for her/him to directly apprise the DG should the need arise. Spectrum management also falls under assurance.
Assurance provides an independent means, reporting to the DG, of assuring critical functions within the Observatory. These functions are in two groupings depending upon the need for direct reporting by that function to the DG. The first group, with a direct line to the DG but line managed by the Head of Mission Assurance, is:

- internal financial audit;
- spectrum management;
- health & safety; and
- environment.

An internal financial audit is provided by a dedicated staff position. It is proposed that this is a secondee, nominated by the Council on an annual basis.

The second group is managed wholly with assurance, with reporting to the DG by the Head of Assurance:

- internal process audit;
- engineering and related standards;
- corporate knowledge management;
- corporate risk management; and
- aspects of corporate responsibility, as adopted by the DG, mandated by the Council.

The assurance function will maintain a risk register, ensuring that it is regularly reviewed and updated by the various departments, and will manage appropriate business continuity and/or disaster preparedness and recovery plans.

This arrangement of assurance ensures that critical functions are directly visible to the DG and can be directed by the DG, but that she/he does not have to line manage or otherwise facilitate and organise those functions.

A role that would normally fall within the scope of compliance, knowledge management, and corporate responsibility (which are assurance functions) is that of Data Protection Officer. Under the Observatory convention, the Observatory has no statutory duty to appoint such a role but has nevertheless chosen to do so. The role is undertaken by the network & IT security specialist and managed within an overall information security management system. Assurance provides the line to the DG necessary for compliance, but the staff resources are wholly within computing.

Assurance also provides a number of services and functions across the organisation. During the construction phase, the assurance team is augmented to provide specific functions relating to construction activities, namely verification, product assurance, safety and environmental supervision.

5.5.2 Purpose and Key Stakeholders

The purpose is to support Observatory mission-critical functions in such a way as to provide the DG with the independent assurance that compliance obligations are discharged. Construction functions, as detailed above, support the programme director.
5.5.3 Delivery Plan

The assurance office will be built up during 2020 and 2021 to address the immediate needs of the early activities relating to construction and an urgent and very specific focus in spectrum management. Recruitment to the roles closely associated with construction activities at manufacturers and on site will take place in late 2021. Corporate functions will be established starting in late 2021 to support routine Observatory activities and respond to policy establishment and implementation requiring assurance. A steady state for the assurance office is expected by 2022.

Subject to a transition driven by reducing workload at the end of construction (particularly through the slowing down of equipment deliveries), the posts will be reduced to an operations era assurance office without the roles dedicated to construction activities. The organisation of the office will remain the same.

The assurance office will be seeded from the SKAO mission assurance team, currently comprising of the Head of Mission Assurance, Head of Health, Safety, Security and Environment, Configuration Manager, Spectrum Manager and System Engineer (verification). The System Engineer (verification) will be redeployed as a matter of urgency relating to early construction activities, to product assurance manager.

5.5.4 Roles and Resources

A short description of each role within the assurance team at SKA HQ is given in Table 12. These staff are complemented by one HSE Manager and one (or more) HSE Officers working within each of the SKA1-LOW and SKA1-MID operations teams in Australia and South Africa, respectively. Site Environment Officers provide oversight on construction activities that have or are suspected to have environmental protection implications. Product assurance engineers advise on parts, materials and process quality issues at SKA1 suppliers and conduct acceptance activities for critical equipment as they are delivered during construction.

The specific allocation of responsibilities and the role titles are subject to change as the model for the delivery of these functions in the telescope host countries is developed further. Those in-country HSE staff will report to the relevant SKA1 Telescope Director but will have a strong dotted-line reporting relationship with the assurance team at SKA HQ through the Head of HSSE.

Table 12: Role descriptions and staff required to support the assurance function of the SKA Observatory.

<table>
<thead>
<tr>
<th>Assurance</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head of Assurance</td>
<td>GHQ</td>
<td>Provides the DG with the necessary assurance of compliance to internal, external, and regulatory requirements and that all processes and procedures are provided insufficient form and are being adhered to. As a member of the senior leadership team, the Head of Assurance will work closely with the DG and other directors in the development of overall policy and strategic planning to ensure the success of the Observatory’s mission. The specific responsibilities are summarised as the oversight, management and planning of:</td>
<td>1</td>
</tr>
</tbody>
</table>

The SKAO’s Spectrum Management strategy is outlined in section 6.4.7.1.1
<table>
<thead>
<tr>
<th>Role</th>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
</table>
| Configuration Manager                     | GHQ      | Has control of the overall SKA system-level configuration and change management system serving the needs of the configuration control board. This role is critical during construction and supports sustaining engineering and upgrades during operations. Sets CM policy and oversees the execution of CM throughout the project. Specific responsibilities are the oversight, management, planning, and execution of:  
  - product/artefact identification and control;  
  - identification and definition of component parts;  
  - document identification and control;  
  - change control process coordination;  
  - configuration audits (including sub-contractor audits);  
  - configuration baselines; and  
  - configuration reporting. |
| System Engineer (Verification)            | GHQ      | Provides strategic guidance regarding the verification of complex systems. The verification of large complex systems is seen as an extension of product assurance and the postholder liaises and co-ordinates with the PA Manager and Configuration Manager to ensure that all associated systems, tools, and procedures are fit for high-level verification with a unified approach and in line with industry best practice for complex systems. Additionally, coordination and integration between hardware and software development activities are provided by this role, together with the other systems engineers. |
| Head of HSSE                              | GHQ      | Responsible for leading project safety and environmental management at the SKA sites in Australia and South Africa as well as the SKA HQ. Specific duties include:  
  - developing, implementing, and reviewing the SKAO’s policies and procedures for HSSE, including appropriate training and audit programmes;  
  - preparing HSE status reports for the DG and Council as required; |
<table>
<thead>
<tr>
<th>Role</th>
<th>Location</th>
<th>Responsibilities</th>
</tr>
</thead>
</table>
| Configuration Officer                    | GHQ      | • ensuring compliance with relevant health, safety, and environmental legislation, both in the UK and in the telescope host countries; and  
  • managing the health, safety, and environmental elements of the business continuity planning process.                                                                                                                                                                                                                     |
| Document Manager                          | GHQ      | Implements and manages components of the business information systems and processes to achieve the objectives of the Observatory’s knowledge management strategy, as well as the adoption of a risk management culture, and catering for business continuity in the event of a crisis. The role will support the effective functioning of the (non-financial) business management system, including quality assurance, and will enable efficient document control systems, records management, information services, enterprise management and dashboarding solutions, policy development, compliance and risk management. In particular, the role will:  
  • develop and implement SKAO’s knowledge management strategy;  
  • provide inputs to the development, management and review of the SKAO information management system (including tools, processes and procedures for information management and document control) to best achieve the objectives of the SKAO knowledge management strategy and non-financial business management system requirements;  
  • ensure an appropriate provision for document handling;  
  • provide inputs to process design, change management and enterprise management, integration, and dashboarding systems;  
  • support monitoring and evaluation functions in the implementation of organisation-wide performance metrics, and compliance;  
  • manage the SKAO risk register, drive internal risk management processes, and ensure compliance with relevant health, safety, and environmental legislation, both in the UK and in the telescope host countries; and  
  • managing the health, safety, and environmental elements of the business continuity planning process.  
|                                           |          |                                                                                                                                                                                                                                                                                                                                                   |
regular risk reporting to external stakeholders whilst supporting the adoption of a risk management culture;

- maintain professional and technical knowledge and benchmarking against industry standards and best practices; and

- Develop policies, procedures, and workflows to support ongoing improvement of SKAO’s information and knowledge management systems.

<table>
<thead>
<tr>
<th>Position</th>
<th>GHQ</th>
<th>Description</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standards Engineer</td>
<td>GHQ</td>
<td>Responsible for curating, maintaining and disseminating standards (both internal and external) already invoked in designs and plans. Together with subject matter experts, the postholder will also assist and act as editor for new engineering standards being developed for SKA and the wider radio astronomy engineering community as appropriate. The role includes acting as sub-librarian under the Document (knowledge) Manager for standards forming part of the knowledge base of the SKA.</td>
<td>1</td>
</tr>
<tr>
<td>Product Assurance Manager</td>
<td>GHQ</td>
<td>Manages day-to-day product assurance activities at suppliers and at construction sites and to act as an acceptance authority for major subsystems. Following construction, the PA Manager runs a system of quality surveillance for engineering materiel used in support of operations.</td>
<td>1</td>
</tr>
<tr>
<td>RFI &amp; EMC Engineer</td>
<td>GHQ</td>
<td>Acts as an internal expert advisor within this discipline and as a technical resource for SKAO. Plays a key role contributing to the coordination and management of RFI &amp; EMC matters within the overall project and the development of project management, system engineering, and wider communication processes within SKAO. This professional is responsible for developing SKAO’s existing RFI &amp; EMC management activities, seeking to promote teamwork in resolving issues and to motivate, coach and develop people in the team to build functional skills in dealing with RFI &amp; EMC related requirements. Also helps to shape SKAO’s strategic RFI &amp; EMC control and management policies. In the wider community, represents the organisation at national and international meetings and conferences, detailing RFI &amp; EMC related project activities and articulating policy positions, and also works in parallel with SKAO’s framework of international spectrum management activities.</td>
<td>1</td>
</tr>
<tr>
<td>Role</td>
<td>Location</td>
<td>Description</td>
<td></td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>----------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>RFI Support</td>
<td>GHQ</td>
<td>Works with the RFI Engineer in supporting the management of RFI activity for the Observatory, specifically for dedicated measurement campaigns related to space-based emissions. The role is distinct from technical support for site RFI monitoring and mitigation.</td>
<td></td>
</tr>
<tr>
<td>Head of Quality Assurance</td>
<td>GHQ</td>
<td>Responsible for the process development framework and the creation, maintenance, development and reporting of performance indicators relating to the quality of Observatory business outputs. The function includes managing business process audits against policies, plans, procedures and standards. The focus during construction will be construction-related processes and products, learning, and capturing lessons which will inform the quality activities at the wider Observatory level post-construction. The postholder will harmonise the approach taken for all existing quality activities into a quality system for the long term. The approach will be standards-based; the objective being that, if mandated, accreditation for ISO 9001 can be achieved with the minimum of additional investment. This role does not have financial audit responsibilities.</td>
<td></td>
</tr>
<tr>
<td>Internal Financial Auditor (secondment)</td>
<td>GHQ</td>
<td>Responsible for auditing the Observatory’s financial processes and accounts on a recurring basis, for internal purposes. Duties are to be defined by the determination of the Council. The role is additional to, and alongside external audit.</td>
<td></td>
</tr>
<tr>
<td>Spectrum Manager</td>
<td>GHQ</td>
<td>Acts as an internal expert advisor within this discipline and as a strategic resource for SKAO. Plays a key role, shaping SKAO’s strategic spectrum management policies. In the wider community, SKAO’s spectrum management specialist represents the organisation at national and international meetings and conferences articulating policy positions, and also works in parallel with SKAO’s RFI and EMC control and management activities. The national-level spectrum management activities include contributing to deliberations regarding radio quiet zones and other national-level radio astronomy service provisions together with the host country counterparts (CSIRO-CASS and SARAO). The international level activities include contributing to deliberations within radio astronomy co-ordination organisations such as</td>
<td></td>
</tr>
</tbody>
</table>
5.6 BE Interactions Between HQ and In-country Operations

In operations activities and steady-state operations, the entire SKA teams in the telescope host countries, Australia and South Africa, will be led by the SKA-LOW Telescope Director and the SKA-MID Telescope Director, respectively. These directors will be employed directly by the SKA Observatory, and each will be supported by an SKA Deputy Telescope Director who will be employed by CSIRO and SARAO, respectively. There will be a small number of IGO employees in each telescope host country in BE roles, with skills and responsibilities spanning finance and procurement, legal, HR, HSSE, IT, and communications. One reason for these staff being employed directly by the Observatory (rather than the telescope host country partner) is to ensure that their professional activities attract the organisational privileges and immunities that are afforded to SKA Observatory as a result of its nature as an IGO.

Relationships between the Observatory and the telescope host country partners will be managed through a variety of mechanisms. The two Telescope Directors will have a very close connection to the partner organisations, CSIRO and SARAO, and will be members of the executive group and senior leadership team. A coordination committee (see section 6.2.1) comprising members from SKAO, CSIRO, and SARAO will meet regularly and will provide a forum in which issues or concerns can be raised, and ideally resolved. Issues will be escalated if necessary, and all parties have committed to an amicable resolution of disputes.

In-country BE staff will report on a day-to-day basis up to the relevant Telescope Director to ensure that they are very much part of the delivery team, and to maximise engagement with the local operations. However, these staff will also have strong dotted-line reporting to the heads of the relevant BE function at SKA HQ in order to ensure consistency of practice across the Observatory and adherence to SKA policy. These connections will also serve to feed information up to HQ regarding the needs and context-relevant in the telescope host countries so that policies and practices can be tailored to ensure that they are fit for purpose and meets the needs of the Observatory.

Business enabling and other operations staff in the telescope host countries will all use the same Observatory systems to conduct SKA business, regardless of whether they are employed by the SKA Observatory directly or by CSIRO or SARAO. SKA will implement a single ERP platform (Unit4 Business World), and all relevant functions will be conducted using that platform.

5.7 BE Delivery Risks

Business enabling functions will operate within an Observatory-wide risk management framework and contribute to the management of Observatory-level risks where appropriate. Stakeholders in risk management of the BE delivery include not only to consumers of BE functions within the Observatory but also to those in CSIRO and SARAO who, by virtue of the partnership agreements, will interact with and make use of Observatory BE services. Specific high-level risks identified in connection with the delivery of this plan and development of the Observatory are presented in Table 13.
Table 13: High-level BE risks identified with delivery of the BE plan.

<table>
<thead>
<tr>
<th>Risk</th>
<th>Mitigation</th>
</tr>
</thead>
</table>
| 1 Business enabling functions operate as individual silos causing inefficiency, inconsistency and process gaps. In particular, BE functions do not meet the needs of the construction project. | • Heads of functions are members of the senior leadership team that meet regularly to share, mutually critique and reach consensus on matters of importance.  
• Extensive use of common technology (ERP, Confluence, Jira, Slack) that will maximise availability and re-use of enterprise data, workflows and interfaces.  
• During transition all development work for the Observatory is coordinated through the transition working group where all BE functions are represented.  
• Common approach to the development and approval of Observatory policies through the SKA policy framework. |
| 2 Misalignment between SKA Observatory and partner organisation policies and practices, leading to inefficiency, increased costs, or inability to deliver operational requirements | • Careful planning, drafting and implementation of partnership agreements to identify potential issues and resolve conflicts at the outset.  
• Implementation of committee structures to oversee the interface between partners/SKAO.  
• Encourage open discussions and early intervention when issues arise.  
• Site Entity Lead, Telescope Director and Site Construction Director to regularly review operating procedures to identify and correct any issues. |
| 3 Divergent processes followed in host countries, due to a lack of stakeholder buy-in, leading to a breakdown of internal controls, or non-compliance with Observatory-wide policies | • Whilst acknowledged that local processes will need to be tailored for the conditions, it is essential that a coordinated and effective internal control system is established and managed centrally. Remote sites will be able to propose local processes that meet minimum policy/control standards.  
• Regular interaction between HQ and sites to ensure compliance with policy.  
• Effective internal audit programme to target high-risk areas. |
| 4 Inability to hire the required BE staff in a timely fashion leads to poorly developed or implemented processes or overworked staff | • Ensure the recruitment plan provides a structured and logical path to recruit the required staff.  
• Active engagement with members to attract talent from the global pool. |
| 5 Business is impacted when key resources are unavailable, the small size in many teams presents a lack of critical mass. This includes the issue of UK business hours limiting response during (in particular) Australian hours. | • Cross-training and pro-active approach to building resilience around mission-critical processes.  
• Engagement of strategic partnerships for additional support, e.g., Unit4 ERP support.  
• Regular staff reviews to understand the likelihood and risk of key person departures.  
• BE posts have largely been replicated in-country to ensure support needs can be met at normal working times.  
• Consideration of out-of-UK-hours coverage for critical BE functions. |
| 6 Misalignment between BE functions and Observatory policy, leading to poor governance, inefficiency, inconsistency, and process gaps | • BE being moulded by the formal transition process and the establishment of new functions driven solely by newly approved policies.  
• Internal audit processes whose criteria arise from approved policies. |
### 5.8 Consolidated BE Resource Tables

The tables below give the staff counts by BE function and year.

**Table 14: BE staff at SKA HQ by function and year.**

<table>
<thead>
<tr>
<th>Function (Roles at GHQ)</th>
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**Table 15: BE staff in the SKA-LOW team in Australia by function and year.**

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Table 16: BE staff in the SKA-MID team in South Africa by function and year.

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<td><strong>Finance</strong></td>
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</table>

5.8.1 Ramp-Up and Down

The tables of BE staffing show the functions at SKA HQ essentially at full strength from 2021, with the resources in place to support the SKA1 construction period which runs over 2021 – 2028. Then in 2028, there is a substantial reduction in the total count of BE staff at HQ, with most of the reduction occurring in the procurement team that decreases from a peak of 11.5 FTE to 3 FTE from 2029. There are also small reductions in finance and HR (at SKA HQ).

In Australia and South Africa, the ramp-up of staff whose primary role is to deliver BE related outcomes starts in 2021 and attains full strength in 2024. It then plateaus over the period corresponding to the peak construction activity 2024-2027. The in-country counts of BE staff then fall back to their long-term levels at the end of construction and are expected to remain steady from 2029 onwards.

There is a much more substantial reduction in total SKA Observatory staffing (see §8) as the Observatory transitions from SKA1 construction into the operations phase. A small number of construction support positions transform into long-term operations roles, some others continue in a greatly reduced programmes team, and a significant number end as the construction phase winds up.

5.9 BE Costs

A significant proportion of BE-related costs are those associated with paying the staff who perform BE functions. Non-staff costs, broken down by year and by the four budget areas, are given in Table 43. The consolidated, total, BE costs are given in Table 17.

Table 17: BE-related costs by year.
6 Observatory Operations

6.1 Objectives and Key Performance Indicators

6.1.1 Delivery of Transformational Science

The Observatory convention [AD8] states (Article 5, paragraph 1):

The SKA project shall be designed to be capable of transformational science, with a combination of sensitivity, angular resolution and survey speed far surpassing current state-of-the-art instruments at relevant radio frequencies.

The primary success metric, as a measure of the SKA’s role in making fundamental scientific discoveries and facilitating overall scientific progress, will be the number of published, high-impact, peer-reviewed scientific papers using SKA data. These papers will be tracked, and their numbers and impact compared against the productivity of other major observatories.

A suite of scientific and operational success metrics is needed to guide the management of an observatory, and there exists a wealth of literature on this subject. The following sections provide an illustrative and non-exclusive list of some of the metrics that could be used for the SKA. It is noted, however, that conventional observatory metrics will require careful interpretation and tuning for the SKA due to the anticipated use of commensal observing, which allows multiple science projects to be carried out simultaneously (§6.4.4.2.6).

High scientific impact often results from the exploitation of unique observational capabilities. The SKA will offer such unique capabilities, primarily due to the large increase in collecting area over existing facilities, a superior imaging capability and the opportunity for multiplexing observations. In order to maintain this leading position, a vigorous SKA Observatory Development Programme (SODP) will be implemented. This programme will provide the Observatory with the designs of upgrades to existing capabilities and the introduction of new capabilities, commensurate with the evolving ambitions of the SKA user community. The SODP will be described elsewhere within this SKA Observatory Establishment and Delivery Plan.

6.1.2 Scientific Success Metrics

Several scientific success metrics will be monitored once the Observatory becomes operational:

- the over-subscription of observing time is a measure of community demand for access to the facility. This metric will be determined during each time-allocation cycle;
- the number of publications featuring SKA observations and results or enabled by SKA resources. This metric will be subject to defined acceptance criteria, including peer review, and is a measure of the Observatory’s productivity. This metric will be tabulated at least annually through a combination of web searches and manual reviews of the literature, and will also count papers that include SKA data obtained from the SKA science archive;
- the number of citations to qualified SKA publications is a measure of scientific impact. This metric will be tabulated as required;
- the number of publications or citations per unit cost of operations is a measure of value for money;
- the degree to which archival use of SKA science data products are (re)-used. This metric will measure how often a data product is used by users other than the originating project team. This can be traced to the productivity of SKA science data products through cross-matching with publications; and
- reproducibility of SKA science data products. This metric will measure how complete the workflow description is that is linked to each SKA data product. The definition of this is to be determined but must reflect the completeness of the provenance information for each data product and accessibility of the software used. This is related to how well SKA science data products adhere to the FAIR principles (https://www.go-fair.org/fair-principles/) of being findable, accessible, interoperable and reusable.

This list is not exhaustive and is expected to evolve over time; it nevertheless encapsulates the primary drivers for the operational model. The SKA will adopt values of Open Science currently being discussed and formulated in the community.

These metrics can be analysed with different amounts of granularity: e.g., over-subscription per member state, or the number of publications per SKA telescope or science mode. In particular, the number of papers published in high-impact journals (e.g., Nature, Science) and the number of high-impact papers (e.g., those with citation rates in the top 1% of all refereed papers world-wide) are measures of the Observatory’s delivery of transformational science.

In addition, metrics that follow the public interest in the SKA through the news and social media will also be tracked.

6.1.3 Operational Success Metrics

Scientific success and operational success are intimately linked: a highly efficient observatory, for example, will enable more science projects to be completed.

The following indicative list of operational success metrics will be monitored once the Observatory becomes operational:

- system downtime due to faults;
- system downtime due to unavailability of computational resources;
- system downtime due to planned maintenance;
- operational availability;
- operational availability of specific capabilities (specific bands and specific observing modes);
- observing efficiency (the total execution time spent on projects – science or commissioning/engineering – compared to the elapsed time to collect those date);
- observing project completion;
- availability of the SRC network; and
- safety record.

This list encapsulates the primary drivers for the operational model. However, it is not exhaustive and will certainly be added to and will evolve over time.

6.1.4 Accountability and Reporting

The Observatory Convention states:

- The Chairperson shall convene the meetings of the Council in accordance with its Rules of Procedure. The Council shall meet as and when required, but not less than once per year. (Article 8, paragraph 12)

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4 https://ec.europa.eu/research/openscience/index.cfm?pg=open-science-policy-platform
The annual reports submitted by the DG, and the papers provided to the Council for its meetings, will report on progress against the objectives of the Observatory. A set of key performance indicators will be developed and reported to enable monitoring and oversight of the Observatory’s performance.

6.2 Constraints and Assumptions

6.2.1 Operating Constraints

In this section, several factors that limit or constrain the operation of the SKA Observatory are presented. Operation of the SKA telescopes will be carried out in the host countries and in accordance with a collaborative operational model being developed between the SKA Observatory and the organisations representing each of the two site host nations, guided initially by a memorandum of understanding. SKAO will collaborate with CSIRO in Australia and SARAO in South Africa. As engineering and science operations will be carried out under the auspices of these agreements, the term SKAO shall be understood to refer to operations or maintenance staff working within this partnership, regardless of their specific employer. Any change to this assumption will be agreed separately.

Figure 6. Collaboration model of the SKA Observatory with CSIRO and SARAO for the operation of the SKA1-LOW and SKA1-MID telescopes.
A driving principle is that the two SKA telescopes shall be operated as a single Observatory. The SKAO, therefore, has a critical role of ensuring consistency across the two collaborations, the implementation of operations in two different telescope host countries, and the two quite different telescopes. It is anticipated that a “coordination committee” comprising senior operations staff from SKA GHQ, SKA1-LOW and SKA1-MID will be established as one of the mechanisms to assist with coordination of both the CSIRO and SARAO collaborations, and ensuring continued unity of purpose across all three sites and partner organisations for the delivery of the SKA Project (see Figure 6).

6.2.2 Host Country Agreements

The SKA Observatory will consist of the following physical infrastructure components:

- a GHQ situated at Jodrell Bank, UK;
- SKA1-LOW, an array of dipole antennas and central processing facility at the Murchison Radio Observatory, and a science processing centre in Perth, in Western Australia; and
- SKA1-MID, an array of dishes and central processing facility in the Karoo region of South Africa, and a science processing centre in Cape Town.

In addition, there will be establishments that will provide scientific and technical support for SKA1 operations. In particular, the main establishments in each country will be:

- a science operations centre;
- an engineering operations centre; and
- a science processing centre.

As per the hosting agreements between SKAO and the Governments of Australia and South Africa, these establishments will be made available to the SKA in support of its construction and long-term operations. The SKA Observatory will engage in a leasing arrangement to pay for the use of these centres. The functional structure of the observatory, showing these centres, is described in §6.3.

A host country agreement document covers a broad range of agreements that together specify the mutual responsibilities and obligations between the SKA Observatory and a host country through the construction, operations, and ultimately the decommissioning and site restoration of the Observatory facilities. Broadly, the host country and SKA Observatory responsibilities are outlined in Table 18.
Table 18: Host country and SKA Observatory responsibilities as outlined in the host country agreements.

<table>
<thead>
<tr>
<th>Host Country Responsibility</th>
<th>SKA Observatory Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Provision of access to the telescope sites, assets and infrastructure (granted through licenses, permits, leases, or property instruments).</td>
<td>• Execution of construction, operation, and maintenance of SKA1 in compliance with local regulations.</td>
</tr>
<tr>
<td>• Secure necessary rights to enable a grant of licenses or leases.</td>
<td>• Be responsible for all aspects of the SKA1 Project that are not the responsibility of the host country, including management and governance, compliance with regulatory processes, recruitment/management/administration of SKA Observatory staff and contractors, decommissioning/demolition and restoration of the telescope site, outreach/communication/promotion activities within the host country.</td>
</tr>
<tr>
<td>• Provide required registers of environment and heritage.</td>
<td>• Operate and maintain all equipment required for the implementation of the SKA1 project.</td>
</tr>
<tr>
<td>• Provide radiofrequency protection with respect to the telescope sites.</td>
<td>• Comply with relevant state and federal laws and regulations.</td>
</tr>
<tr>
<td>• Coordinate interaction with all concurrent users of the site, including indigenous land users.</td>
<td>• Compliance with the terms for access to the sites, including any radio frequency interference standards and protection protocols.</td>
</tr>
<tr>
<td>• Coordinate construction and operation of other radio facilities on-site to ensure construction and operations according to the Convention.</td>
<td>• Provision of adequate insurance cover for the telescopes, works, staff, contractors, assets, and infrastructure.</td>
</tr>
<tr>
<td>• Maintain stakeholder relationships with national and local governments.</td>
<td>• Support host country stakeholder relationships.</td>
</tr>
</tbody>
</table>

The provisions of the hosting agreements are binding on SKA1 operations.

6.2.2.1 Operations Policy

An operations policy [AD9] has been negotiated by the members as a Tier-2 document under the Observatory convention. This policy specifies the functional structure of the Observatory from the perspective of telescope operations and constitutes a governing document for the operation of SKA1.

As noted above (§6.2.1), an operational collaborative model will be developed.

6.2.2.2 Access Policy

An access policy [AD10] has been negotiated by the members as a Tier-2 document under the Observatory convention. The detailed implementation of the access policy is being developed as a Tier-3 document, the SKA1 access rules and regulations.

Associate members will be treated in the same way as members for the purposes of access. Thus, throughout this document, reference to “members” should be interpreted as “members and associate members”.
6.2.2.3 Safety, Health, and Environment

SKAO is committed to protecting personnel from accidental death, injury, or occupational illness and safeguarding systems, infrastructure, and property from accidental destruction or damage while executing its engineering and science requirements.

The vision is to go beyond eliminating preventable illnesses, injuries, business losses, and environmental harm due to unplanned events in SKA premises and sites. This includes improving the wellbeing of all involved in project work by addressing SKA’s impact on climate change and waste, preventing pollution, enhancing biodiversity, and encouraging inclusion and healthy living during the design and construction phases and beyond. As an example, the anticipated key threats and hazards which will need to be eliminated or mitigated include (but are not limited to):

- vaccine-preventable endemic diseases;
- vector-borne diseases (e.g. malaria); and
- pandemics/epidemics (e.g. influenza, cholera, Ebola, COVID-19).

Good health, safety, and environmental performance will be integrated as a core element in every planning, design, and construction operation to achieve the SKA Observatory’s aim of being safe and secure. The protection of the health and safety of everyone involved in or affected by its work, and the protection of the local and global environment, is important to the SKA Observatory.

Health, safety, and environmental performance will be given the highest priority at all times by systematically identifying, assessing and managing HSE risks, monitoring performance against targets, and publishing the results.

Engagement with all our staff, partners, stakeholders, and suppliers will ensure that everyone is enthusiastically involved in managing risk, securing success, and acting as an ambassador for the Observatory’s realistic and practical vision.

The HSE management plan\(^5\) [AD1] is to serve as a vehicle to communicate the high-level quantitative and qualitative characteristics of the approach to safety and environmental protection to be taken by the SKA Observatory. It describes the roles and responsibilities, competence requirements, and methods for HSE implementation by all SKA Observatory contractors, consultants, and suppliers. For SKA-MID there is a specific responsibility to comply with the Integrated Environmental Management Plan for the SKA1-MID site, and the staffing plan includes dedicated resources to ensure that this requirement is fulfilled.

The HSE management plan mainly draws on requirements from [RD17] and [RD18]. It is also inspired by similar plans from other major telescope projects. The plan shall apply to any activity relating to design development and procurement, with future revisions focusing on the transition to procurement and acquisition, construction and manufacturing, and operational and maintenance phases. It is intended to relate to physical or virtual work developed in any science, engineering, or manufacturing sense.

NOTE: Different national statutes have a variety of safety acronyms such as H&S, HSE, OHS and SHE. The SKA Observatory recognises these terms are frequently interchangeable. Provided a reasonable and logical equivalence can be demonstrated and agreed with the SKA Head of Health, Safety, Security & Environment (HSSE), it is not expected that our partners, stakeholders or suppliers radically amend

\(^5\) In some project documentation reference may have been made to a ‘health and safety plan(s)’ or equivalent – for the sake of clarity this term can be considered equivalent to the HSE management plan.
language used in their existing safety documentation. Generally, the use of the word “safety” should be considered synonymous with ‘health and safety’ for the purpose of reading and understanding this document.

Owing to the diversity of engineering cultures present in the participating organisations, and the cost and risk of supplanting satisfactory existing practices where these are established, the HSE management plan does not seek to invoke unnecessary change – only to emphasise and re-iterate principles.

Each stakeholder organisation shall write a specific HSE plan for their respective activity, considering this plan and calling upon appropriate applicable and reference documents. These HSE plan(s) shall be issued to the relevant line management authority for review and acceptance before any significant work activities start, if not already issued previously. Note: the term “organisation” is used extensively to represent any partner or stakeholder (e.g., contractor/consultantupplier) involved in the SKA project.

Inevitably, that some overlap between safety risks (safety hazards) and the project risk management activity will occur. It is important that all significant safety hazards have visibility to senior managers who are responsible for project risk but that also ALL safety hazards have visibility to the overall SKA Observatory Head of HSSE.

Similarly, some overlap between safety hazard management and product safety will inevitably occur. Product safety is an integral part of product assurance and, therefore, the product safety detail requirements of the SKA product quality assurance plan [AD5] shall interpret and at the detailed level take precedence over this document. It is however proposed that the HSE plan should take the highest priority in the hierarchy of safety subject to compliance with applicable national regulation.

In the case of product safety, the HSE plan high-level requirements should be compatible with the SKA product quality assurance plan but the detailed requirements for product safety will be found and referenced in this latter plan.

Other risk areas such as quality assurance and asset integrity can be expected to appear in the output from safety hazard analysis. It is an objective of the SKA to ensure the highest levels of quality performance in the planning, the design and the implementation of the SKA. It is envisaged that CSIRO and SARAO should be viewed as in partnership with the SKA and their relationship with the SKA should not be governed via an SLA, expedited via an operations collaboration agreement. Such a collaboration will not only foster goodwill and ownership, but also mitigate potential conflicts of interests.

6.2.2.4 Radio-Quiet Environment

The SKA1 telescopes will be located within radio-quiet zones in Australia and South Africa. These zones are globally unique resources. Both countries have obligations through the hosting agreements (§6.2.2) to protect the sites from radio-frequency interference arising from external influences within their jurisdiction and from other facilities on the sites. The SKAO will be responsible for controlling self-interference arising from the operation and maintenance of the SKA telescopes, and for limiting radio pollution of the sites by the SKA equipment or activities that may affect other facilities.

An EMI/EMC standard for the SKA, including details of implementation and enforcement, has been developed and agreed [AD2]. This standard is binding upon SKA1 operations.
6.2.2.5 Data Flow

One of the unique challenges of the SKA is its extremely high data rate: it is currently estimated that each SKA telescope could produce approximately 350 PB of science data each year in routine operations and that the long-term SRC archive might grow at a rate close to an exabyte\(^6\).

In July 2013, the SKA Board imposed a cap on the construction cost of SKA1, and in so doing defined the scope of the project to include the generation and storage of data products by the science data processor (SDP). No provision was made at that time for the archiving of these data, their distribution to users, nor for computational facilities to enable users to undertake further data analysis, both of which are mission-critical if the SKA is to deliver on its scientific promise. Full scientific exploitation of the SKA requires that a research ecosystem is in place for efficiently translating the large data volume into science results. This research ecosystem must have three components that are not within the scope of the SKA1 Observatory:

- computational capacity for processing and science analysis;
- storage capacity for archiving Observatory and advanced data products; and
- local user support.

In April 2016, the SKA Board determined that these functions should be provided by a set of SKA regional centres (SRCs). The SRCs are to be funded and operated by the regions\(^7\) in which they reside, and they are therefore not formally within the scope of this project: the relationship between the SKAO and the SRCs is to be collaborative in nature, based on a memorandum of understanding and an accreditation framework. The advantages of this approach are:

- it recognises the understandable preference of any region to invest in infrastructure within its borders;
- resources can be tailored to the local needs of the regions, which are diverse across the SKA partnership;
- it offers the opportunity for early community engagement with the SKA, not only for astronomers but also for data scientists and software and computing experts;
- it offers the opportunity to leverage existing computational infrastructure across the SKA partnership; and
- it widens the pool of potential funding sources.

The essential functions of the SRCs are:

- to give SKA users access to SKA data, in compliance with the SKA data access policy;
- to provide the computational and data management resources for the archiving of SKA data;
- to provide SKA users with processing infrastructure to enable the scientific analysis of SKA data;
- to form a federated environment which allows transparent data access across the SRC network, giving access to data products across the global science archive to all members of the SKA community; and
- to provide users with local user support.

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\(^6\) These numbers are very approximate – the actual data delivery rate out of SDP and the long-term SRC archiving growth rate depends on the science programmes undertaken at SKA and how these data products are used in SRCs.

\(^7\) The term “region” is used here generically to refer to a SKA member state, a jurisdiction within a state, or a grouping of states; thus, “regional” could be replaced by “national” in the case of a single state.
Some regions may wish to provide additional, non-essential functions through their local SRC (e.g., regional point of contact; outreach and publicity; development activities). Such additional functions are optional and at the discretion of the regions.

Development and implementation of the SRC concept is the responsibility of the SRC steering committee. For the purposes of this plan, it is assumed that an ensemble of SRCs will be in place as currently envisaged (see §6.4.5). Resources are identified for the coordination of this activity. The SRC steering committee has developed a draft white paper describing its vision for the structure, functions and scope of the SRC network [RD24]. The white paper was presented to the SKA Board at BD-32 in May 2020 and discussed further at BD-33. At BD-32 the SKA Board noted that the SRC network is critical to the delivery of SKA science and endorsed the SRCSC white paper, noting that agreement on the SRC governance structure is still to be achieved. At the time of writing, consideration of SRC Governance continues and while broadly relevant, this plan is more dependent on the respective responsibilities of SKAO and the SRC network, and the operational interface between them. The SRCSC membership includes senior SKAO operations staff, and there is general agreement between this plan and the SRCSC on operational issues, but some details may change as governance arrangements crystallise and formal agreement with the SRC network will be required.

6.2.3 High-Level Assumptions

High-level assumptions that have been made in the development of this plan are listed in Table 19. These assumptions are distinct from design choices, which are presented in the following chapters.

Table 19: High-level assumptions.

<table>
<thead>
<tr>
<th>No.</th>
<th>Assumption</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>SKA Phase 1 will be delivered, in compliance with the SKA1 Construction Proposal.</td>
<td>N/A</td>
</tr>
<tr>
<td>A2</td>
<td>An ensemble of SRCs will be provided by the SKA members, in compliance with governance arrangements and technical interfaces and requirements to be determined.</td>
<td>§6.2.2.5, §6.4.5</td>
</tr>
<tr>
<td>A3</td>
<td>The SKA telescopes will be capable of 24-hour operation.</td>
<td>§6.4.4</td>
</tr>
<tr>
<td>A4</td>
<td>The proprietary period will be 1 year from the date of notification to the user that observatory data products are available.</td>
<td>§6.4.4.1</td>
</tr>
<tr>
<td>A5</td>
<td>The existing working patterns for the precursor telescopes ASKAP and MeerKAT will be adopted. Routine, on-site operational support will be provided on a 5-day working week.</td>
<td>§6.4.6.7</td>
</tr>
<tr>
<td>A6</td>
<td>The SOCs, SPCs and EOCs will be delivered by the host countries in compliance with SKA requirements. They will be leased following a ‘value for money’ principle. The SKA will not own these facilities at the end of any lease.</td>
<td>§6.2.2</td>
</tr>
<tr>
<td>A7</td>
<td>A SKA-VLBI consortium will be established to help facilitate VLBI observing with the SKA.</td>
<td>§6.4.4.3</td>
</tr>
</tbody>
</table>

6.3 Observatory Functional Structure

As noted in §6.2.2, the SKA Observatory will be comprised of three infrastructure components: the GHQ in the United Kingdom, the SKA1-LOW telescope at the Murchison Radio Observatory in Western Australia, and the SKA1-MID telescope in the Karoo region of South Africa. The operation of both telescopes is supported by activities at several facilities in the two host countries. The functional structure of the Observatory is shown in Figure 7.

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8 To be decided by the Council
For SKA1-LOW, the station-beamforming equipment for those stations located in the core are in the central processing facility (CPF). For the clusters of remote stations located along the spiral arms, the signal processing equipment is located within 36 nearby remote processing facilities (RPFs), similarly located along the spiral arms. All data are then transported to the correlator in the CPF where they are correlated or formed into beams for pulsar search, pulsar timing or VLBI observing. For SKA1-MID, the data from the dishes, both in the core and those along the spiral arms, are transported to the CPF for correlation, or beamforming.

The SRCs are included in this structure because even though they are outside the scope of the Observatory construction project, they are a critical functional component of the Observatory. As discussed in §6.2.2.5, a collaborative operational partnership will be set up between the Observatory and the ensemble of SRCs.

Figure 7. Functional structure of the SKA Observatory.

A list of the functions to be carried out by the Observatory, and the allocation of those functions to the GHQ and the two telescopes, is presented in Table 20. The functions have been assigned to three categories as follows:

- business enabling functions: those functions that are essential for operating the Observatory as an organisation;
- Observatory operations: those functions that are directly connected with operating the two SKA telescopes and generating science data products for release to the community; and
- development support: those functions that are required to run the SODP.
Table 20: Functional allocations between the GHQ and the two SKA telescopes.

<table>
<thead>
<tr>
<th>Category</th>
<th>Function</th>
<th>LOW</th>
<th>GHQ</th>
<th>MID</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Business Enabling Functions</strong></td>
<td>DG Office</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Senior leadership</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Long-term policy</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Relationship management</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IGO Legal and business affairs</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Communications, public outreach, branding</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spectrum management, RFI policy &amp; standards, ITU</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Corporate services (finance, HR, IT, audit, etc.)</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Procurement</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Health, safety, &amp; environment</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Secretariat for external bodies</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Observatory Operations</strong></td>
<td>Engineering policy &amp; standards</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Engineering support (spares, logistics, configuration, etc.)</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Hardware support (mechanical, electronic, instrumentation)</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Computing and software management &amp; strategy</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Software engineering (architecture, quality, toolset, observation management)</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Software engineering (controls, data acquisition, scientific computing)</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Computing infrastructure (operational systems)</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Science operations (telescope-specific)</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Science operations (observatory-wide)</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Helpdesk</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interface to SKA regional centres</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Scientific research</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Site operations (land management, infrastructure maintenance, RFI monitoring, etc.)</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td><strong>Development Support</strong></td>
<td>Scientific strategy</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Upgrade programme management</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Interface to SKA development centres</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For each telescope, the operational activities will be carried out at a number of facilities, as indicated above in Table 20. These facilities are as follows:

- **Science operations centre (SOC):** These will be located in Perth and Cape. At the time of writing, it is expected that the SOC in Australia will be in the Australian Resources Research Centre building and the SOC in South Africa will be in a new building on the site where the NRF iThemba LABS is located. All telescope-specific science operations activities will be based here: this includes telescope control and observation execution by the Telescope Operator, carrying out a quality assessment, and ensuring data are of sufficient quality for delivery to the SRCs. Software support and most administrative functions will also be based here.

- **Science processing centre (SPC):** These will also be located in Perth and Cape Town (exact locations TBD). In Australia, it is anticipated that this will be the Pawsey Centre, under some form of contract. In South Africa, no such data centre presently exists, and SARAO is planning to construct one to meet SKA requirements adjacent to the SOC at the iThemba LABS site. The SPCs are high-performance computing centres that will host the science data processors.
• Engineering operations centre (EOC): These will be located in Geraldton in Australia and Klerefontein in South Africa. They will function as the administrative bases for on-site activities and host mechanical/electrical/instrument workshops and RFI chambers.

These centres are identified in the Hosting Agreements as host country deliverables. For the purposes of this plan, it is assumed that these centres will be provided and will be compliant with SKAO requirements.

The allocation of in-country functions to these three centres is indicated in Table 21.

Table 21: Functional allocations within each SKA Telescope.

<table>
<thead>
<tr>
<th>Category</th>
<th>Function</th>
<th>SOC</th>
<th>SPC</th>
<th>EOC/Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business Enabling</td>
<td>Senior leadership</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functions</td>
<td>Relationship management</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IGO Legal and business affairs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Communications, public outreach, branding</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corporate services (finance, HR, IT, audit, etc.)</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Procurement</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Health, safety, &amp; environment</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Telescope Operations</td>
<td>Engineering support (spares, logistics, configuration, etc.)</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Hardware support (mechanical, electronic, instrumentation)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Computing and software management &amp; strategy</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Software engineering (controls, data acquisition, scientific computing)</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Computing infrastructure (operational systems)</td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Science operations (telescope-specific)</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scientific research</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Site operations (land management, infrastructure maintenance, RFI monitoring, etc.)</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.4 Observatory Operations - Implementation

6.4.1 Requirements Flow down And Principles of Operations

Table 22 presents a set of principles, derived from the operations policy (§6.2.2.1) and the access policy (§6.2.2.2), to govern the design of SKA operations. This Operations Plan represents the implementation of these principles and the set of L1 requirements generated in the SKA1 operational concept document [RD2]. The flow down of requirements from the L0 science requirements [AD6] is described in the L1 system requirements specification [AD7] and illustrated in Figure 8.
Table 22: SKA Observatory principles.

<table>
<thead>
<tr>
<th>SKA Observatory Operations</th>
<th>The SKAO will be operated as a single organisation, with a GHQ at Jodrell Bank Observatory in the UK and Facilities in each of the host countries.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duplicate of staff between the two telescopes should be minimised. Common functions between the two telescopes should, in general, be based at the GHQ, except where the Council decides otherwise.</td>
<td></td>
</tr>
<tr>
<td>Each host country will appoint a site entity for the purposes of delivering some of the responsibilities of the host country, as set out in the relevant hosting agreements.</td>
<td></td>
</tr>
<tr>
<td>SKA Global Headquarters</td>
<td>Corporate or BE functions will be based at the GHQ.</td>
</tr>
<tr>
<td>The GHQ will undertake activities that are common between the two telescopes and that are not best undertaken in proximity to the telescopes and engineering staff.</td>
<td></td>
</tr>
<tr>
<td>Operation of the SKAO in the Host Countries</td>
<td>Operations of the SKAO in the host countries will be performed via a cooperation agreement between the SKAO and an operating partner in the host country.</td>
</tr>
<tr>
<td>The cooperation agreement shall be approved by the SKAO Council on the proposal of the DG. The DG will report on progress towards the objectives of the cooperation agreement.</td>
<td></td>
</tr>
<tr>
<td>Science Processing Facilities</td>
<td>The SKAO will make agreements with science processing facilities in each host country.</td>
</tr>
<tr>
<td>SKA Regional Centres</td>
<td>Members and associate members may establish SKA regional centres to support the user community in their country, region, or scientific field.</td>
</tr>
<tr>
<td>SKA regional centres shall reach an agreement with the SKAO regarding their roles and obligations.</td>
<td></td>
</tr>
<tr>
<td>SKAO Science Programmes</td>
<td>Time allocation will be based on scientific merit and technical feasibility, evaluated via a common time allocation process.</td>
</tr>
<tr>
<td>Time will be made available for key science projects, principal Investigator-led projects and DG’s discretionary time. Additional Time categories, with associated principles of access, may be introduced by the SKAO Council.</td>
<td></td>
</tr>
</tbody>
</table>
| **Allocation of Telescope Time** | The DG is responsible for Time allocation, advised by a time allocation committee (TAC).  
The SKAO Council may direct the DG to allocate time on the telescopes to other entities, such as states, international organisations and institutions that are not members or associate members of the SKAO.  
The DG will appoint the membership of the TAC and may include individuals from outside SKAO membership.  
The DG can appoint such domain-specific subgroups as necessary in order to obtain the best possible advice for time allocation. |
| **Member Time** | The SKA Observatory will operate on the principle that access is proportional to members’ share in the project.  
The Council will agree on a metric to enable monitoring and review of the level of member access. Performance against that metric will be monitored and reviewed by the SKAO Council. The SKAO Council may direct the DG to take measures to more closely align that member’s access with their share in the SKAO project.  
The SKAO Council will make provision to allow access for SKAO staff. |
| **Open Time and Access for Non-members** | Provision will be made for open time, at a level to be determined by the SKAO Council and may set a time limit on the level of time allocated to scientists from a single non-member.  
The process for allocating open time will operate in the same manner as for member time. |
| **Availability and Ownership of Data Products** | Observatory data products are to be made openly available after a suitable proprietary period to be determined by the SKAO Council.  
The DG will have the discretion to alter the proprietary period in individual cases in consultation with the PI.  
All data taken by the SKA are owned by the SKAO. |
6.4.2 SKA Observatory Operations Organisational Structure

The organisational structure of the SKA Operations group is shown in Figure 9. It shows how the reporting structure flows down from the DG through the director of operations. The relation between staff at the GHQ and the two telescope sites is also shown. All staff at each of the SKA1-LOW and SKA1-MID telescopes report up through to the Telescope Director, who in turn reports directly to the director of operations.

![Organisational Structure Diagram]

Figure 9. Organisational structure for the SKA operations group. The location (GHQ, SOC or EOC) for each lead role and their functional area is also shown.

6.4.2.1 GHQ Operations Monitoring Centre

An operations monitoring centre will be located at the GHQ building that will provide a mirror of telescope operations at each of the SKA telescopes. This room will not be used for remote control of the telescopes. It will provide a view of telescope operations without interrupting the Telescope Operators and observing teams. The Telescope Operators for each of the SKA-LOW and SKA-MID telescopes will be located in the science operations centres in Perth and Cape Town, respectively.

The main purpose of the operations monitoring centre is to provide a direct link between staff operating the telescope and the GHQ. Each Telescope Operator (or others) will be able to talk directly with domain experts at the GHQ (e.g., for fault diagnoses or troubleshooting). All displays, logs, and monitors that are available at the SKA1-LOW and SKA1-MID telescopes will also be mirrored to the operations monitoring centre.

It is anticipated that the operations monitoring centre will also play an important role in public outreach events, as well as to exhibit and demonstrate the ongoing operations to SKA staff and visitors.
6.4.3 Science Programmes

The SKA will undertake science observations that enable the generation of science data products (§6.4.4.6) in accordance with the access policy outlined in §6.2.2.2. For a detailed description of the science case and scientific motivation for the SKA, please refer to section 2 of the SKA Construction Proposal [RD1].

A wide range of scientific programmes that utilise the capabilities of the SKA have been identified that will lead to fundamental advances in our understanding of the Universe. An indication of the breadth and depth of that science programme is given in [RD4].

As noted within the access policy, it is foreseen that a wide range of science programmes will be supported, both in terms of observing time requirements on the two SKA telescopes as well as high-performance computing (HPC) requirements to generate the associated Observatory data products (§6.4.4.6).

The relevant range of total observing time needed for any particular programme will vary from less than 1 hour to several thousand hours. The programmes requiring the largest observing time allocations will be classified as key science projects (KSPs), while those with smaller time allocation needs (exact number of hours is still TBD, but 100-hours is often used as a guide) will be classified as standard principal investigator (PI) projects (§6.4.4.4.2). The guidelines for proposal preparation and submission in both categories will be distributed within a regular call for proposals prior to each observing cycle (§6.4.4.4), although it is anticipated that KSPs and PI projects will have different cycles.

6.4.3.1 Joint SKA Programmes Relying on Both SKA1-LOW and SKA1-MID

The review of high priority science objectives for the SKA (documented in [RD4]) led to the identification of a wide range of science programmes that would benefit from observations undertaken with both the SKA1-LOW and SKA1-MID telescopes. Together such programmes may account for up to about 50% of the total SKA science time. The science categories currently identified for which this capability is most important are:

(a) transients, to track in real-time the evolution of highly time-variable source properties;
(b) pulsars, to most effectively detect new pulsar populations in complementary portions of the sky (with different dispersive characteristics);
(c) continuum, to fully characterise the spectral energy distributions (SED) of different source classes;
(d) HI science, including HI intensity mapping and HI-absorption work to study the ’21-cm forest’ and reveal the large-scale structure of the Universe;
(e) magnetism, to measure the polarised SED and reliably recover intervening Faraday depth features; and
(f) physics of the Sun-Earth system including imaging of shock waves, coronal mass ejections, and resolved magnetohydrodynamic waves.

The proposal submission and time allocation process described in §6.4.4.4 will support the successful completion of such joint programmes.
6.4.4 Science Operations

The SKA will be the world’s largest observatory in the centimetre to metre wavelength range, greatly surpassing the current generation of telescopes in sensitivity, field of view, and survey speed. As discussed above, the SKA is intended to be a high-impact and transformative observatory, commensurate with the scale of investment by the members. The science operations element of the Observatory has been designed to enable these ambitions. The SKA will operate for 24 hours every day to maximise its scientific productivity and provide access to as much of the southern sky as possible throughout the year. The SKA will be operated as a single, integrated Observatory running two telescopes, SKA1-LOW and SKA1-MID, without observers present at the telescopes. Although the telescopes operate over different frequency ranges using different technologies, there will be opportunities for joint observing programmes. To drive efficiency up and overhead down, the SKA Observatory will run a flexible observing programme to allow it to continue to be scientifically productive in the face of adverse circumstances (e.g., weather, faults, etc.), and to multiplex its observing programmes as much as possible.

6.4.4.1 Access to Data and Resources

Access to the SKA Observatory and its resources shall be guided by the access policy (§6.2.2.2) and the access rules and regulations (currently being developed). These broadly follow the basic principles that:

- time allocation shall be a fair process driven by the scientific excellence of proposals and will be robust against, and be able to resolve, conflicts of interest wherever they may arise;
- the priority for the time allocation process is to ensure that the science programme of the SKA is of the highest quality, undertaking high-impact science projects; and
- access will be proportional to members’ contributions to the SKA Observatory.

A traditional allocation of “telescope time” is misleading in the SKA context, since what is really allocated to projects are observatory resources. For the SKA Observatory, an allocation of “telescope time” alone does not accurately or proportionately reflect the investment that is necessary to arrive at a calibrated Observatory data product (ODP). The computational resources throughout the signal chain will also need to be allocated to ensure sufficient processing time and capability to deliver the required ODPs. In other words, proposals will need to justify not only the telescope time required but also their use of other resources, especially the computing resources of the SDP and SKA regional centres (see also [RD24]). A metric that describes how the resources used by a project count against a member’s share of the SKA project will be developed in the SKA Observatory access rules and regulations document.

Throughout their lifetime, the ODPs will remain the property of the SKA Observatory. All scientists of the member nations of the SKA Observatory shall have access via the SRC network to ODPs they are authorised to. Each ODP will be subject to a proprietary period wherein access to that ODP will be limited to the PI and Co-I(s) of the originating project. The proprietary period will be specified in the access rules & regulations but is currently assumed to be 1-year from the date that the PI is informed the ODPs are available. Following the expiration of the proprietary period, the ODPs will be publicly available. The SKA DG will have the discretion to alter the proprietary period for any ODP on a case-by-case basis.

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9 Some ODPs, for example arising from commissioning or calibration observations, will have no proprietary period.
There will be no direct access for users to science data products at the SKA Observatory itself. Access to all science data products (Observatory and advanced data products) will be via the SRCs.

6.4.4.2 Observing

Observations will be executed within subarrays (see §6.4.2.7) which are a subdivision of an SKA telescope that can be scheduled and operated independently.

6.4.4.2.1 Scans, Scheduling Blocks and Observing Blocks

The SKA will utilise three execution concepts in its operations: scans, scheduling blocks (SBs), and observing blocks. The definitions for these, and how they relate to each other, are provided below.

Scan:
- the scan is the atomic unit of execution; e.g., a 10-minute track on a target is an executable scan;
- a scan is a period during which astronomical data are being continuously acquired; and
- the configuration of the subarray is fixed during a scan.

Scheduling Block (SB):
- the SB is the atomic unit of observation planning and contains all information needed for that purpose, i.e., telescope, instrument, correlator and SDP configurations;
- an SB consists of more than one scan, and long integrations can be built up by repeating a number of sequential scans within SB instances, drawn from the parent SB;
- users interact with their project and observation design at the SB level, e.g., target lists, calibration choices, frequency and bandwidth configurations, SDP pipeline parameters;
- an SB should include all information necessary for it to be executed successfully (i.e., without error) at the telescope and to produce observatory data products (i.e., they must have an associated calibration schema that includes the necessary calibration information for an observation);
- SBs may have a range of durations and may be executed many times;
- an SB executes on a subarray, which may include the whole available array; and
- the length of an SB will vary based on the science case (and may be subject to a maximum length, TBD) but may typically take 1-2 hours to execute.

Observing Block:
- observing blocks can act as containers of SBs that are necessary to achieve the science goals of the project; and
- the SBs in an observing block can be related by certain scheduling constraints or breakpoints in the observing, such as:
  o SBs that need to be observed in a specific order;
  o SBs with very specific scheduling constraints (e.g., observe the SKA1-LOW SBs before those on SKA1-MID);
  o repeat the SB at a range of hour angles; and
  o observe a given number of SBs from the observing block and then move to observe from another observing block.

Scheduling blocks are generated using the observation design tool (§6.4.5.1) based on the contents of the submitted proposal if that proposal is successful and becomes a project. A proposal may have a number of different scientific programmes (e.g., continuum survey and spectral imaging). During SB
generation, each programme is mapped to an observing block which contains the set of observations required to achieve its goals. Each observation is represented by a single SB.

All observations that generate data on the SKA telescopes will have a project and SBs associated with them. This includes data taken using a slice of the system for engineering purposes.

6.4.4.2.2 Observing Modes

A number of observing modes will be supported by the SKA to enable the scientific goals of the Observatory and its community to be realised. These observing modes can be differentiated between imaging and non-imaging modes. The observing modes shall be:

- continuum imaging;
- spectral/zoom window imaging;
- pulsar search;
- pulsar timing;
- dynamic spectrum;
- transient search; and
- very-long baseline interferometry (VLBI).

Independently of the observing modes, there are different ways in which the telescope carries out observations, i.e., tracking modes (§6.4.4.2.2.3). Furthermore, there will be special observing modes to allow for a fast reaction to targets of opportunity, triggered events, etc.

6.4.4.2.2.1 Imaging Modes

There will be two imaging modes available. Near-field phase corrections for the solar system, or other, objects will be applied as needed.

Continuum imaging: Designed for imaging areas of the sky over a broad bandwidth. The bandwidth chosen is configurable and for SKA1-MID it is limited by the receiver chosen. Spectral resolutions can be configured from 5.4 kHz for SKA1-LOW and 13.4 kHz for SKA1-MID. As well as the correlated visibilities, this mode is able to deliver the autocorrelations to support intensity mapping observations. All four Stokes parameters can be imaged.

A dedicated fast-imaging pipeline will produce snapshot images, at low latency and high time resolution, to search for radio transients with variability ranging from seconds to hours. Detections are recorded in a Transient Source Catalogue and comparisons will be made with previously catalogued objects. The detection of a transient may trigger an International Virtual Observatory Alliance (IVOA) alert, dependent on its parameters.

Spectral line/Zoom window imaging: Spectral line imaging provides between 52,500 and 65,536 linearly spaced channels across the frequency band. Zoom windows allow for higher spectral resolution images to be obtained, down to several hundreds of Hz. The number of simultaneously available zoom windows available for SKA1-MID will depend on the available processing and data transfer resource available. These windows contain between 14,000 and 16,384 linearly spaced channels that can be configured across the available bandwidth. SKA1-LOW can have up to four zoom windows with bandwidths ranging between 4 and 256 MHz. This mode is able to deliver the autocorrelation as well as the correlated visibilities. All four Stokes parameters can be imaged.
6.4.4.2.2 Non-Imaging Modes

Pulsar and transient search: This mode searches for periodic pulses over a range of possible dispersion measure values, including acceleration searches for highly relativistic pulsars. It is also capable of searching for single pulses. The pulsar search pipeline sifts through and identifies candidates and generates a catalogue of those as a science data product. Detections of new single pulses and new pulsars may produce IVOA alerts and may trigger the dump of the transient buffer. This mode is capable of searching the visible sky from each SKA1 telescope by using a large number of tied-array beams (500 for SKA1-LOW and 1500 for SKA1-MID) to achieve high sensitivity and survey speed.

Pulsar timing: This mode converts tied-array dual-polarisation voltage beams into folded integrated pulse profiles of pulsars to accurately measure the time-of-arrival (ToA) at which a fiducial phase of a pulsar’s periodic signal arrives at the phase centre of SKA1. The ToA is used to generate the timing model for a given pulsar. This mode processes up to 16 dual-polarisation, beamformed voltage streams simultaneously and independently. They can be formed from up to 16 different sub-arrays.

Flow-through: This mode is designed to record raw tied-array beam data for offline analysis (e.g., at SRCs), to allow for testing of specialist techniques and algorithms that require full phase information in the incident signal. The output product is a configurable portion of the total bandwidth of the dual-polarisation voltage beam signal.

Dynamic spectrum: This mode produces a generic, high time-resolution, dynamic spectrum that may be used for a broad range of scientific applications. The resultant data product is a time-versus-frequency spectrum with configurable time and frequency resolutions, that may contain all or a subset of the Stokes parameters.

VLBI: This mode provides independently steerable tied-array beams to participate in VLBI imaging and non-imaging observations, with other radio astronomy observatories located around the globe. This mode provides ultra-sensitive elements (at µJy noise level) to the VLBI networks, at milli-arcsecond angular resolutions. At least four dual-polarisation VLBI beams can be formed from one or more subarrays, including up to the full array. Polarisation corrected and RFI masked tied-array beam voltage data is recorded in VDIF format compatible with external VLBI correlators, for inclusion in either real-time or post-observation correlation.

For SKA1-LOW, VLBI beams can be formed with a maximum bandwidth of 256 MHz per polarisation, per beam. For SKA1-MID, visibility data are produced simultaneously within each VLBI-mode subarray to provide calibration solutions to establish beam coherence and to enable standard imaging with the subarray in interferometric mode. The standard VLBI bandwidths are available up to 200 MHz per polarisation, per beam. For increased bandwidth, the appropriate number of VLBI beams should be configured with the same pointing.

Transient Buffer: A buffer continuously records a certain bandwidth of raw voltage data, in dual polarisation, from all the antennas/stations to capture transient events. The characteristics of the buffer (e.g., bandwidth and size) depend on the upstream configuration of the SKA1 telescope. The buffer dump is triggered when a virtual observatory (VO) alert is received, either internally from the SKA1 telescope (e.g., following the detection of a single pulse), or externally from other observatories across the electromagnetic spectrum and/or multi-messenger facilities (e.g. gravitational waves, neutrino experiments). The data that are dumped by the buffer start a few seconds before the event was detected and lasts for 900 seconds or 60 seconds, for SKA1-LOW and SKA1-MID, respectively.
6.4.4.2.3 Telescope Tracking Modes

Data for each observing mode can be collected using different telescope tracking modes. The tracking mode should be chosen depending on the characteristics of the scientific project, providing the highest observing efficiency for the depth required. There will be four tracking modes available.

**Sidereal Tracking:** In this mode, antennas/stations from a subarray observe a target position by tracking it at sidereal speed.

**Non-Sidereal Tracking:** In this mode, antennas/stations from a subarray observe a target position, tracking it at a speed that is different to the sidereal rate, e.g., for objects in the Solar System.

**Wide Area Scanning:** This mode is for observing large areas of the sky with shallow integrations. This mode will be used when the overheads of using other observing modes to obtain a large map are significant. The region to observe is scanned at higher than sidereal speed, performing parallel scans (i.e., raster scans). The scan area can be defined (within the SB) in either (RA, Dec), (Az, El) or galactic coordinates.

**Drift Scanning:** In this mode, the antennas/stations in a subarray do not track the sky but are fixed relative to the Earth, i.e., they point to a fixed position defined in (Az, El) coordinates, while the sky moves across the beam at the sidereal rate.

6.4.4.2.3 Targets of Opportunity, Triggered Events, and Overrides

The ability to acquire new objects quickly, in response to alerts that have been triggered by events either externally or internally to the SKA (e.g., targets of opportunity (ToOs), transients, etc.), is an important science driver for the SKA. Follow up on potential SKA discoveries by other observatories will be crucial for multi-wavelength and multi-messenger studies. The SKAO will use the VOEvent protocol to communicate alerts between SKA1-LOW and SKA1-MID telescopes, to publish alerts externally, and to subscribe to VOEvent announcements from other observatories or researchers in the science community.

For approved projects, the response to different triggered events will be dependent on the scientific ranking of those projects as assigned in advance during the proposal review process, a judgment that will be based on the proposal’s scientific merit, impact, and urgency. These projects will have pre-defined SBs to allow their observation with minimal delay. Once triggered, the SB for that project will have any late-binding information (typically target position and name) added to it and will be available for observing. The SB will be scheduled for execution according to its ranking at an appropriate time commensurate with its scheduling priority, just as any other project. Projects that may result in trigger events will need to include rules for issuing VOEvents.

A project may have override status due to its importance and urgency (an evaluation that will emerge from the proposal review process), e.g., a supernova explosion in a nearby galaxy. It is anticipated that the majority of trigger events will not have override status. A project that is triggered with override status will immediately enter the top of the currently executing schedule (with maximum 1-second latency), displacing other projects. If the environmental constraints are satisfied, then the SB will begin executing immediately, aborting currently executing SBs if necessary, to obtain the required resources. Decisions on which SBs to abort will be based on their scientific priority and the amount of resource that will be freed. The override status may differentiate between immediately aborting and stopping the currently executing SBs at the end of the current scan.
For the majority of cases any late-binding information will be in the form of a target’s position and name, or a late update to the ephemerides where the orbit of a body is not well known at the time the proposal was written (or when the SB was last updated). All pertinent information will need to be included in the VOEvent that triggered the SB.

VO alerts may also be received as requests from researchers in the community. As there is no existing project, that request for observing will go directly to the DG, or their delegate, and if approved for execution a project and SBs will be created for it. In most cases, such an event will likely be of very high importance and override status may be assigned at the DG’s discretion. A response system will be put in place to ensure decision and implementation within 12 hours of receiving the request.

6.4.4.2.4 Calibration

Calibration [RD22] is a specific activity needed to render raw data into science data products that may then undergo further scientific analysis. The basic framework for calibration is the Hamaker-Bregman-Sault measurement equation, including direction-dependent effects and making use of frequency-dependent Global and Local Sky Models. The calibrations can be broadly classified as follows:

A priori calibrations:
- Flagging for non-operational equipment, antenna not on source, RFI in known bad channels or above-defined thresholds, antenna shadowing, etc.
- Ionospheric Faraday rotation (determined from total electron content and a model of the geomagnetic field).
- Gain-pointing direction curves (gain-elevation for MID).
- Antenna/station voltage patterns.
- Application of pointing models.
- Application of delay models.

External calibrations (using pre-determined sky models):
- Delay (parallel and cross-hand).
- Bandpass.
- Polarization leakage.
- Absolute flux-density scale.
- Complex gain.
- Calibration transfer between bands, beams, spectral configurations.
- Autocorrelation spectra from interferometric observations.

Note that RFI flagging will be performed iteratively during the calibration loop.

Self-Calibration:
Applied iteratively to refine both amplitude and phase (or delay) calibration and sky model during the imaging process (again interleaved with RFI flagging).
- Direction-independent phase and amplitude.
- Direction-dependent (correcting for non-isoplanatism in the ionosphere, inaccuracies in the beam or station model, residual pointing errors):
  - A and AW-projection.
  - Facet-based imaging.
  - Peeling.
  - Pointing self-calibration.
Real-time calibrations:

These require analysis and feedback on-line and are applied by sub-systems other than SDP.

- Station calibration (SKA1-LOW), applied by LFAA/MCCS.
- Reference pointing (SKA1-MID), applied to the dishes.
- Complex gain calibration to be applied in the beamformers.
- Polarization leakage calibration (to determine Jones matrices for PST, PSS or VLBI beamforming), also applied in the beamformers.
- Gain monitoring using noise diode (SKA1-MID); applied in the correlator.

Array Calibrations:

These require significant blocks of observing time and are executed periodically by the Observatory to determine parameters required for every element of the array and applied in the a priori calibrations described above.

- Dish pointing (SKA1-MID).
- Dish gain-elevation (SKA1-MID).
- Antenna locations and cable delays.
- Beam models (SKA1-MID: holography; SKA1-LOW: raster scans).

Many calibrations are determined and applied offline by the science data processor ICAL pipeline; others are executed infrequently or, conversely, applied online. The Observatory will maintain an ongoing calibration programme that will periodically undertake routine calibration observations (see Array Calibrations above, for instance) at various cadences. This calibration programme will also include the appropriate monitoring of absolute flux scale calibrators (such as PKS B1934-638) and other standard calibrators (particularly at the high frequencies of SKA1-MID where a Global Sky Model (GSM) is less likely to be used. The details of and policies for this calibration programme are under development.

The strategy for carrying out these calibrations is discussed in detail in §6.4.4.5.5. Calibration data will be public and shareable between projects and SBS, if appropriate.

6.4.4.2.5 Timing Conventions

The SKA Observatory will base its timing convention on the use of active hydrogen masers as reference clocks. Two timescale realisations are calculated in parallel, master, and back-up, with the ability to switch between the two in case of failures. This solution applies to both telescopes, SKA1-LOW and SKA1-MID.

The SKA timescale will be traceable to Coordinated Universal Time (UTC) using Global Navigation Satellite System receivers to accurately determine the time offsets with respect to UTC. From the observer’s perspective, any timing constraints in SBS will be expressed in UTC, Local Sidereal Time and/or in local time for the telescope site in question.

The SKA timescale will need to apply leap second corrections to its network clocks and caesium clock. Leap seconds are announced six months before the event and can be applied at 23:59:59 on the last day of June or December of the year as required, whenever UTC has drifted more than 0.6 seconds behind the mean solar time. The leap second correction could be an automatic process or be manually commanded. The addition of the leap second means that UTC will read 23:59:60 before reaching midnight. Implementing the leap second shall not interrupt SKA operations, and the Observatory will keep monitoring the integer difference between UTC and International Atomic Time (TAI).
6.4.4.2.6 Commensal Observing

Commensal observing will have a significant impact on the scientific productivity of the SKA. Three different types of commensal observing are defined:

- **Data Commensality**: multiple projects can use the same Observatory data products but for different science goals, as recommended by the TAC and approved by the DG.
- **Observing Commensality**: multiple projects can use the same field of sky, and telescope/instrument configuration, but they each need different observatory data products:
  - the commensal projects would result in different observatory data products from the same SB, e.g., two different pipelines acting on the same set of visibilities, or, non-image processing and spectral line imaging products.
- **Multiplexed Commensality**: the ability to use multiple subarrays and/or tied-array beams to concurrently observe different fields of the sky.

There is no sharing of time between commensal projects. Each commensal project will be charged for the execution time used (see §6.4.4.2.10), up to the limit of the time awarded by the TAC, e.g., if 6 hours are used to execute an observation for two commensal projects, they are each charged 6 hours (not 3 hours).

Whether observing and multiplexed commensality are feasible at any instant in time is dependent on the availability of the signal and data processing resources needed to generate the desired number of observatory data products for each of the commensal projects.

At the proposal submission or observation design stage, it is not possible to know with certainty whether a particular project can be executed commensally or not, and as such PIs are not required to identify or label their proposals or projects as commensal. The nature and number of commensal projects at any point in time will always depend on the telescope resources available, as well as the relative scheduling priorities of other potentially commensal projects. All decisions with regard to commensal projects will be taken at the cycle planning and observation planning stages (§6.4.4.5.2) by SKA operations staff.

6.4.4.2.7 Subarrays

There will be projects for which the science goals do not require the entire telescope array, e.g., observing a very bright target or multiple objects across the sky. The SKA will be able to configure into subarrays and/or tied-array beams to enable this multiplicity of observing. The general definition of a subarray is:

> A subarray is a subdivision of an SKA telescope that can be scheduled and operated independently of other subarrays. A subarray constitutes a set of resources and can be as large as the whole telescope array, or a single constituent item. A subarray is only prevented from being created by resource constraints.

Resources are capable of being controlled to perform certain tasks. In the context of the SKA, a resource could be a dish, a beam, or a slice of the correlator. Resources are schedulable entities. As

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10 However, the KSP science programme will be designed to maximise commensality amongst the different projects.

11 Although, clearly, a PI will be able to flag SBs within their own project as commensal.
such, the number of subarrays that the SKA can support is resource-limited. The control and configuration of subarrays will be via the telescope manager.

In practice, subarrays will fall into two operational categories: engineering subarrays and astronomy (or science) subarrays. An engineering subarray will generally be used for maintenance, repair, test and commissioning purposes, and may not need an entire system “slice” with end-to-end functionality, but this is not precluded. For instance, a set of dishes without the need for signal or data processing may be configured into an engineering subarray. Conversely, an astronomy subarray requires end-to-end capability.

Subarray templates will be developed from which users will select when writing their proposals and designing their SBs. These templates will continue to evolve to reflect array usage patterns and scientific demand and to increase commensal opportunities. For example, pulsar search subarrays might only use inner receptors and pulsar astronomers will want as many inner receptors as possible, but the overall scientific throughput will be higher if another subarray is made available containing (possibly) a small number of inner receptors with spiral arm receptors to allow high-resolution work to be carried out commensally (§6.4.4.2.6). Having subarray templates rather than a ‘free-for-all’ approach will constrain the complexity and simplify the scheduling.

6.4.4.2.7.1 Independent and Dependent Subarrays

It will be possible for subarrays to be operated independently of each other. This allows different types of science programmes to run concurrently on the telescope and brings operational advantages, e.g., testing software or firmware updates on a live system slice of the telescope without impact on the ongoing science programme.

The architectures of the SKA1-LOW and SKA1-MID correlators/beamformers are significantly different such that the behaviour of subarrays in the two telescopes will differ in detail. For instance, the SKA1-MID correlator with its Frequency Slice Architecture allows the sharing of correlator resources between subarrays. This leads to concepts of independent and dependent subarrays, as illustrated in Figure 10.

The upper panel of the figure depicts conceptually what may be a typical commensal (multiplexed) configuration of the SKA1-MID telescope with independent subarrays. Subarray 1 is allocated with dish resources configured to observe in Band 1, while Subarray 2 is allocated dishes configured for Band 2. Two SBs will be executed on Subarray 1 (observing commensality), SB1 for imaging and SB2 for non-imaging (pulsar search, in this instance). Subarray 2 is observing in Band 2 using, for example, spectral zoom windows as defined by SB3. The SDP, as a formal part of the signal chain, not only produces the observatory data products (defined in each SB) but also provides calibration solutions in real-time. All observing details are defined within the SBs, and the scheduling tool (§6.4.4.5.4) ensures that all resources are available before configuring any subarrays and executing the observations. These SBs do not need to be from the same project.

In the SKA1-MID correlator, two different subarrays can be utilising the same set of frequency slice processors as long as they are both using the same observing mode (e.g., imaging or pulsar timing), irrespective of the receiver band upstream. This presents a situation where two subarrays have a dependency between them as shown in the lower panel in Figure 10. Subarray 1 is allocated dish resources configured for Band 1 observing for two SBs: SB1 for continuum imaging and SB2 for pulsar search. Subarray 2 is allocated dish resources configured for Band 2 observing by the two SBs selected (SB3 and SB4). In the CBF, SB1 and SB3 can use the same set of resources for imaging, while SB2 and SB4 will use the same beamforming resources (in the CBF) for pulsar search. Once more, none of the
SBs need to originate from the same project, and the scheduling tool ensures that all resources are available before configuring the subarrays and executing any observations.

In general, it is anticipated that a mixture of dependent and independent subarrays will be in operation, e.g., two dependent subarrays sharing resources in the CSP, with a third subarray allocated resources that are independent of those in the other subarrays. Operationally, this allows the observatory to utilise an engineering subarray for testing or maintenance while the rest of the telescope is still following the observatory’s science programme with astronomy subarrays.
Figure 10. Resource allocations for independent (top) and dependent (bottom) subarrays on SKA1-MID. For the independent subarrays, Subarray 1 is executing imaging and pulsar search SBs commensally, while Subarray 2 is executing an imaging project. For dependent subarrays, both are executing imaging and pulsar search SBs, sharing the same resources in the CBF for imaging (SB1, SB3) and beamforming for pulsar search (SB2, SB4). The Telescope Manager handles the resource allocations to the subarrays based on the information within each SB. The SDP (dashed lines) is an exception as it handles its resource management internally, although the Telescope Manager is informed by SDP that resources are available to complete the data processing before it sends any SB for execution.
SKA1-LOW uses different technology, and allocated resources are shared between separate subarrays (Figure 11). For any particular subarray (up to a maximum of 16), all observing modes can be processed simultaneously, and each active subarray is processed in parallel. All field-programmable gate arrays (FPGAs) in the correlator are used simultaneously to ingest the data and process the different subarrays and observing modes. For SKA1-LOW, a subarray is configured with beams rather than stations.

Every FPGA in the SKA1-LOW correlator processes a certain bandwidth. As such, although it is possible to select a subset of FPGAs to be used as part of an engineering subarray, this will be at the cost of some bandwidth to other active subarrays.

6.4.4.2.8 Tied-Array Beams

It is possible to operate the SKA1 array as a single element (i.e., a virtual single dish) rather than as an interferometer. The full array or any subarray can operate as a single element through the coherent summation of signals from the individual antennas or stations in the array/subarray. As a result, one or more (up to 500 for SKA1-LOW and 1500 for SKA1-MID) tied-array beams of improved sensitivity can be produced from the same or different subarrays, each with independent pointings on the sky, and configured and operated independently of each other. Tied-array beams are used for many
scientific applications, such as observations of transients and pulsars, and allows SKA1 to participate in VLBI observations, providing a very sensitive element to VLBI networks.

Beamforming makes use of real-time calibration to minimise efficiency losses caused by misaligned signal phases, atmospheric effects and polarisation impurity, as well as state-of-the-art RFI detection and excision algorithms.

6.4.4.2.9 Custom Experiments

It is the SKA’s principal aim to undertake transformative science of the highest possible impact. This may present itself in the form of an experiment that is not directly supported by the design of the SKA, or that requires a higher level of support and expertise than is provided under normal operations. Custom Experiments provide a framework within which unique and innovative ideas can be performed on the SKA.

Custom experiments will normally require an extension of existing SKA functionality or performance by the addition of hardware or software. Custom hardware may be used for data acquisition and bespoke software for pipeline data reduction may be made available via the SDP as long as they interface appropriately with the SKA while adhering to health, safety, and environmental, and network security policies of the SKA.

Custom experiments will be subject to the same review process as other proposals, with the TAC assessing the scientific impact, urgency and priority of the proposed experiment. This will be supported by a technical review of the custom experiment proposal to provide a statement as to the impact that the experiment will have on normal operations of the SKA Observatory, assessing the observatory resource required to support it. The review process will consider any risk or inefficiency (e.g., wasted or unscheduled telescope time) that may be inherent in scheduling custom experiments and ensure that any equipment meets established standards. This technical review will normally be undertaken by SKA staff, or external experts if necessary.

Supporting custom experiments can be costly, thus the technical review process will only consider recommending a custom experiment if the necessary observatory resources are available and if the subsequent impact on observatory operations is negligible and/or warranted. The custom experiment team are responsible for conforming to existing SKA interfaces and will provide, and test, any additional hardware and software necessary for the success of the experiment. All custom experiment teams will be responsible for providing data products (not raw data) suitable for archiving and must abide by the same proprietary period policy as other SKA data. This requirement to archive data products will be waived only in exceptional circumstances.

6.4.4.2.10 Time Accounting

The execution time to observe scheduling blocks shall define the time charged to projects. This time shall be tracked and then subtracted from the remaining allocated time on that project. The total elapsed time will also need to be accounted for with the Telescope Operator responsible for ensuring that the elapsed time recorded tallies with the actual time available (e.g., 24 hours) during an observing period/shift. The elapsed time will be accounted for against various categories. These times will be recorded in the shift log and reported in the observing report filed at the end of each telescope operator shift.
Definitions of elapsed and execution time are:

**Elapsed Time:** the ‘wall clock’ time that has passed during any operational activity.

**Execution Time:** the elapsed time to carry out an executable action (e.g., a scan, a pointing).

**Chargeable Time:** the sum of execution times that go towards the observation of an SB and is charged to the project.

Note that even though calibration observations may be present within SBs, in general, the execution time for calibrations will not be charged to the projects (see §6.4.4.5.5). Due to commensality and subarrays, the total chargeable and execution time in a single 24-hour period, say, can be greater than 24 hours as there will be more than one project being executed at the same time. The elapsed time will still be 24 hours.

To track the observatory’s activity and observe efficiency, the following time accounting categories will be used:

- configure,
- calibration,
- science,
- engineering,
- commissioning,
- fault,
- weather,
- idle,
- other.

This establishes a clear demarcation of activities during a typical observing period. For instance, the aim of the engineering category is to identify any data that are taken specifically for the purposes of engineering or maintenance and the time elapsed for these should be accounted for separately from that for obtaining science or calibration data. Some activities that may not result in data on disks (e.g., fault finding) but the time elapsed for those activities still needs to be accounted for. The “Idle” category will allow the operations team to track those resources that are available but are left idle because, for instance, the scheduled observations have not utilised them. This will be a measure of how efficient the planning algorithms are to make the most use of the available resources, or how constrained the subarray templates are.

It is important that all time periods and gaps are appropriately labelled and tagged in the observatory’s shift log tool (see §6.4.4.5.4). The “other” category is to be used for activities that do not easily or clearly fall into one of the standard categories – a clear description in the shift log tool will be required to describe what did occur.

At the end of each observing period, an observing report will be generated, archived and automatically shared with operations staff. This report should contain a log of all observations carried out or attempted, whether successfully or otherwise. The report should also contain any narrative from the Operator(s) on events that occurred during the observing period and reports on any faults encountered and remedial action taken (if at all). Links to the tickets giving a detailed description of the faults will be included in the report and the log. The Telescope Operator will ensure that the total elapsed time reported tallies with the total available time (e.g., 24 hours for a daily report).
6.4.4.3 VLBI

The SKA-VLBI capability provides ultra-sensitive elements (at μJy noise level) in the form of tied-array beams to the VLBI networks, at milli-arcsecond angular resolutions. Standard interferometer imaging to enhance the calibration, and/or complement the science return will be available. As for other observing modes, VLBI can be performed commensally with other observing modes (e.g., PSS, PST, imaging) as long as the resources exist to support these modes.

The SKA Observatory will enter into appropriate agreements (e.g., MoUs) with VLBI partners in order to facilitate SKA-VLBI observations. Furthermore, by the time SKA1 becomes operational, it is assumed that an SKA-VLBI consortium, with a global perspective and membership, will be established. At the time of writing discussions of this consortium are in their infancy but it is currently anticipated that this body will support SKA-VLBI observations, provide the VLBI equipment and ensure that VLBI correlators are prepared to include SKA data. The SKA DG will determine how the SKA Observatory will be represented in this consortium.

SKA participation in VLBI experiments will be subject to the standard access rules and regulations, with no requirement for proposers to be members of the envisaged SKA-VLBI consortium. It will be necessary for the SKAO to establish policies regarding a coordinated time allocation process, data rights, proprietary periods, length of time a VLBI proposal may remain active, coordination of observations, and correlation with the external VLBI partners. Policies such as these may be established directly with each of the VLBI partners, or, if all SKA-relevant VLBI networks and facilities agree to be members of the proposed SKA-VLBI consortium, may be coordinated through the consortium.

VLBI will be available through both PI and KSP proposals, assessed through the SKA’s normal proposal review process. All VLBI proposals will be coordinated proposals but may also fall under any of the other three subcategories (target of opportunity, long-term proposal, joint SKA proposal – see §6.4.4.4.2). Proposals will include details of the VLBI array required to fulfil the science goals and proposers will be responsible for obtaining time on the other facilities, as appropriate. Once approved, projects will be scheduled in close collaboration with VLBI partners, taking into consideration the various scheduling constraints of the respective facilities, as well as science requirements of the project.

6.4.4.3.1 VLBI Technical Considerations

SKA-VLBI projects will make use of at least four independently steerable VLBI beams formed from a core subarray (or subarrays); most science cases will use the inner core (8 km baselines with 70-80% total sensitivity) but in principle, SKA1-MID can beamform the whole array (up to 150 km baselines) while SKA1-LOW is limited to 20 km baselines. The choice of core subarray size is a trade-off between the field of view (FoV) and the sensitivity in the beams but is ultimately limited by the beamforming stability. A higher number of VLBI beams in each subarray (e.g., 8 or 10) could enhance the astrometry products by an order of magnitude compared to what is currently achievable (up to 1 microarcsec) and would make observing fields with a high density of targets more efficient. A standard set of VLBI specific subarray templates will be made available to cover the range of sensitivities and FoV required.

For projects requiring broadband or simultaneous observations using multiple bands, VLBI beams may be utilised from several core subarrays (i.e., core partitions) with similar resolution and sensitivity. Some VLBI projects will benefit from the addition of several individual SKA antennas (i.e., single-element subarrays) with long SKA baselines to better utilise the SKA resources for some configurations, it may also be advantageous for VLBI experiments to use a core subarray providing the...
beams plus several SKA antennas at larger baselines as individual elements to provide short uv-spacing data. The subarray phase centre’s position and time are referred to as ITRF and UTC, respectively. The SKA will need to track positions and velocities of the subarray centres due to continental drift.

Polarisation-corrected and RFI-masked tied-array beam voltage data is recorded in VDIF format compatible with external VLBI correlators, for inclusion in either real-time or post-observation VLBI correlation. The standard VLBI channel bandwidths are available up to 64 MHz for SKA1-LOW and 128 MHz (and the non-standard 200 MHz) for SKA1-MID. The total bandwidth of the LOW beams is 256 MHz per polarisation, covering most of the band, while for SKA1-MID the maximum bandwidth is 5 GHz per polarisation, for 2 beams, (or 2.5 GHz for 4 beams). SKA1-MID is able to provide more beams but with decreasing sensitivity, up to a maximum of 52 beams per subarray with 200 MHz bandwidth, per polarisation. The external data network used to transfer data from the SKA to the VLBI correlators will depend on whether the SKA-VLBI observation is performed in real-time (e-VLBI) or not.

In order to successfully participate in VLBI experiments, the SKA needs compatible VLBI equipment and the VLBI correlators need to be upgraded to support multi-beam instruments with broad bandwidths (outside the scope of the SKA project). It is currently anticipated that a SKA-VLBI Consortium will be able to attract the funding to provide the VLBI element (including appropriate hardware and software) for the SKA Observatory, for both SKA1-MID and SKA1-LOW telescopes. This equipment will be located at the science processing centres in Perth and Cape Town.

The VLBI equipment will be completely integrated into the SKA system and monitor and control functions using the Tango framework [RD7]. The SKA Operator will supervise the proper functioning of the VLBI equipment during the observations (as with the rest of SKA subsystems), and open tickets in case of problems. VLBI observations will operate in standard record/playback mode or e-VLBI mode (streaming of VLBI data to the external correlator, for real-time correlation); data transfer to the VLBI correlators can be initiated automatically using the Flexbuff VDIF recorder. Therefore, no additional operator support will be needed for VLBI observations or data transfer at the SPCs. The VLBI equipment is expected to be low maintenance but may require the occasional non-specialist maintenance (e.g., faulty disks and power supply replacement). Major upgrades and maintenance are expected to be performed by the anticipated SKA-VLBI consortium.

A VLBI observing project will contain the necessary timing constraints as to when the observation needs to be executed with other stations in the VLBI network. The PI initially generates a standard VLBI VEX (VLBI Experiment) file12, which is common for all the participating observatories and contains a complete description of the observation, including:

- observatory characteristics (e.g., geographical coordinates, wrap limits, etc.);
- target and calibrator information (e.g., coordinates, flux density, etc.);
- technical information about the observation design (e.g., type of VLBI data acquisition terminal, bandwidth, channels, etc.); and
- the detailed observing schedule specifying the observing and calibration scan times in UTC.

This VEX file will be attached to the SKA VLBI observing project submitted to the observatory, ingested and parsed to extract the necessary technical details needed to generate the associated SBs. The original VEX file will remain associated with the SB so that it is accessible by the observation design tool (§6.4.4.5.1). The SKA will be able to accept changes to observing details if users submit an updated VEX file (e.g., change of calibrator) up to a few hours before the observation starts, an action that will automatically update the associated SB accordingly.

12 It is anticipated that version VEX2.0 will be available when SKA1 becomes operational and will support multi-beam instruments such as the SKA1 and will detail the intent of every scan (i.e., target vs. calibrator).
Telescope time is conventionally awarded to PIs via a multi-phase process (see Figure 12). In phase 1, a proposal is prepared and submitted by a PI and their Co-Is, followed by a peer review process undertaken by an independent TAC. If the proposal obtains an award of telescope time, it enters phase 2 as a project where scheduling blocks and technical details can be refined (perhaps following feedback, recommendations or restrictions from the TAC). PIs will, through a common, central utility, be able to prepare and edit draft proposals, and track their active and past projects. In phase 3 the observed data from the correlators/beamformers are processed to generate Observatory data products (§6.4.4.6.1) that are delivered to SKA regional centres for users to access for science extraction and exploitation.

This section outlines the key features of a proposal submission system covering all activities up to and including the recommendation of awards of time and resources by the TAC, with the final confirmation of those recommendations made by the DG. The system is designed to implement the terms of the access policy (§6.2.2.2); the detailed implementation rules are in the draft access rules and regulations (currently being developed).

The Observatory will accommodate both large programmes and conventional PI-driven programmes (§6.4.3). In addition, the process will allow for future new and innovative schemes and campaigns. For the first few years of operations, the SKA will be focussed on key science projects (KSPs) and PI observing programmes.
The process for proposal submission and time allocation for PI projects is described below. It is anticipated that proposals for KSPs will follow similar principles.

6.4.4.1 Proposal Preparation and Submission

A central project database will store all current and historical proposals (PIs and Co-Is will be able to access only their own proposals). A proposal handling tool will provide access to this repository as well as allowing all potential users of the SKA telescopes to prepare a feasible scientific proposal without the need for specialist radio interferometry knowledge (although some radio astronomy knowledge must be assumed).

This will be achieved by allowing the PI to choose from a selection of templates from a library that they can use to construct the technical elements of their proposals. This template library will include examples that cater for a breadth of science goals – with different spatial and spectral resolutions and varying sensitivity characteristics – for the observing modes available for the cycle and incorporating the appropriate subarray configurations for those science goals. It is anticipated that this library will grow with time and experience of operating the SKA telescopes.

The basic constituents of a proposal will include title, author list, abstract, scientific and technical justifications, data product pipeline requirements, the total integration time estimated using a sensitivity calculator, calibration needs, and access to astronomical databases to resolve names of specific objects and/or their coordinates. An estimate of the resources required at SKA regional centres will also be needed. To aid in the design of observations, the PI shall be able to access a library of standard template configurations (e.g., pulsar timing, deep imaging, and wide-area mosaic) that can be inserted into a proposal and tailored to specific user needs. To facilitate collaboration across globally distributed teams, a PI will be able to delegate editing privileges to co-investigators.
If the science goals of a proposal require the use of both SKA1-LOW and SKA1-MID, then it will be possible to request and justify the use of both telescopes within a single proposal. A separate technical section for each telescope will be required.

6.4.4.4.2 Proposal Types

Any potential user of the SKA will be able to apply for a variety of proposal types. The main categories of a proposal are as specified in the access policy (§6.2.2.2):

**Standard Principal Investigator Proposal (PI)**
A standard PI proposal is an observing proposal initiated following a call for proposals and is typically completed within a single time allocation cycle. Standard proposals are typically submitted by a small team led by a principal investigator.

**Key Science Project (KSP)**
Proposals for key science projects will be for relatively large resources allocations (time and compute) for observing programmes that cannot be completed within a single time
allocation cycle. Proposals for KSPs will (most likely)\(^\text{13}\) be received and reviewed at a time and cadence that differs from the regular call for proposals.

**Open Time (OT)**

There will be a fraction of time available to PIs from member and non-member countries.

**Director-General Discretionary Time (DDT)**

DDT proposals (that could not reasonably have been submitted in the normal cycle) can be submitted at any time needing only the approval of the DG.

The access policy ([AD10]; see §6.2.2.2 and §6.4.1) states that time will be available for proposals from Member nations to apply for KSP and PI time. In addition, there will be a fraction of time available as open time that will be open to both member nations and non-member nations.

There will also be the following subcategories of the proposal:

- **Target of Opportunity (ToO)**
  - These are proposals that require a rapid response to alerts that have been triggered by events either externally or internally to the SKA.

- **Long-term proposal (LTP)**
  - These are for projects that require more than one-time allocation cycle to complete (e.g., long-term monitoring campaigns) but are too short in overall observing time to qualify as a KSP.

- **Joint SKA Proposal (JSP)**
  - A proposal that requires both SKA1-LOW and SKA1-MID telescopes to achieve the science goals. Such proposals may be linked so that observations can be executed contemporaneously.

- **Coordinated Proposal (CP)**
  - A proposal requiring observing to be coordinated with another facility (either ground- or space-based) with user-specified scheduling constraints provided. The SKA Observatory will seek to establish relationships with key, complementary facilities (e.g., ALMA) to facilitate CPs. Proposals for VLBI will be considered as coordinated proposals.

Clearly, some of these categories may apply to more than one proposal. For instance, it may be possible to have a proposal which is both ToO and JSP, or LTP and CP. The policy for SKA staff to apply for SKA time (either as PIs or CoIs) will be defined in the access rules and regulations and approved by the SKA Council.

**6.4.4.4.3 Proposal Review and Time Allocation**

The time allocation process will be managed, coordinated, and supported from the GHQ by the science group with support from science operations. Full details of the time allocation policy and review process are yet to be fully defined, but here we outline the expected process.

Given the expectation of a high volume of proposals from across the SKA member nations, it is likely that the time allocation process will utilise separate panels to review proposals addressing different science themes. The use of templates and proposal validation, described in §6.4.4.4.1, should ensure that all submitted proposals are technically feasible. Following a triage of proposals, SKA operations

\(^{13}\) At the time of writing, a full policy for KSPs has not been determined.
staff will technically assess the remaining proposals to ensure that observing and calibration strategies, for instance, are sound. Of course, the review panels will have the opportunity to request further or more detailed/specific technical assessment on any proposal.

Grades assigned to proposals will require normalisation so that direct comparisons can be made across the science themes, and so that a final merged ranking of all proposals can be constructed. This will also allow comparisons to be made between distinct proposal cycles and as different personnel rotate on and off the panels.

The TAC, with support from the SKA operations team, will be able to use a cycle planning tool to assess how the proposals they are recommending for awards are distributed across the sky for the whole observing cycle. This will help to minimise underutilised areas of the sky while applying a degree of oversubscription to provide some tensioning to the observing programme so that the telescope is always occupied doing the best possible science projects. The tool will also look to the available computing resources at the SDP, as well as in the global network of SRCs. As a proposal is submitted for review it will generate SBs based on the information included in the proposal. By design, there will be sufficient information in each proposal, and generated SBs, to allow the cycle planning tool to identify opportunities for commensality between different projects.

The cycle planning tool will also be designed to ascertain how observing time is being distributed amongst the members and the likelihood that the appropriate fractions go to each, by modelling the likely completion statistic for each project subject to estimates of fault and weather losses.

The cycle planning tool will have the requisite sophistication and access to information (e.g., schedules of known maintenance/engineering events) to explore different strategies to craft the best possible science programme for the observing cycle that satisfies the national and scientific interests of the SKA members and is commensurate, over a time period to be defined, with their contributions to the SKA Observatory.

6.4.4.4.4 Proposal Lifecycle and States

Figure 13 illustrates the lifecycle of a proposal from when the call for proposals is issued to the point where a proposal is accepted or rejected. Once authenticated, a PI is able to create a new proposal or continue working on an existing one.

The states of a proposal are:

Submitted:  
- a proposal that has passed validation and can be considered for review once the call for proposals has closed;  
- a unique identifier code is assigned to the submitted proposal that reflects the proposal cycle that it is being submitted into; and  
- a notification is sent to the PI and Co-I/s acknowledging the successful submission of the proposal (quoting the proposal’s unique identifier code).

Not submitted:  
- any proposal that is still in a Draft state once the call for proposals has closed is flagged as Not submitted.

Under Review:  
- the proposal is in the process of being reviewed and assessed for scientific excellence, technical feasibility, and schedulability; and
• includes the scientific evaluations of proposals by independent peer reviewers, as well as the meeting of the TAC where final recommendations are made.

Withdrawn:
• a proposal may be withdrawn from the Submitted state at any time before the call for proposals has closed, and returned to the Draft state;
• a proposal may be withdrawn from being reviewed via a request to SKA operations;
• only the PI or SKA operations may withdraw a proposal that is currently Under Review; and
• DDT proposals, with no formal submission deadline, can only be withdrawn by the PI or SKA operations.

Accept/Reject:
• the result and final output of the time allocation process;
• notification is sent to the PI and Co-Is reporting the outcome of the review of their proposal, including the official feedback and ranking to emerge from the review process.

While a proposal is under review by the TAC, it will enter and exit from states that are only viewable to SKA personnel supporting the review process. The PI or Co-I of the proposal continue to see their proposal as under review. These ‘hidden’ states will be useful for operations staff to track the progress of the proposal review phase, i.e., how many reviewers have accepted to review each proposal, or the number of reviews that have been received. These states are:

Reviewer not assigned:
• once the call for proposals is closed all proposals enter this state

Reviewer invitation sent:
• a reviewer for a proposal has been identified and an invitation has been sent requesting their assistance in reviewing the proposal within a given timeframe;
• if the invitation is declined, the proposal returns to Reviewer not assigned until a new reviewer is identified; and
• multiple reviewers will be assigned per proposal.

Accepted by reviewer:
• the invitation to provide an evaluation of the proposal has been accepted by the reviewer by the agreed date; and
• for reviews not received in time an extension can be offered, otherwise, the proposal returns to Reviewer not assigned and a new reviewer may be sought.

Review received:
• the final review and evaluation have been received from a reviewer.

Note that it is not explicitly stated here whether the reviewers are internal or external to the TAC as this process will work equally well for either situation. A policy for time allocation, which will describe how proposals will be peer-reviewed, will be developed and presented in the SKA Observatory access rules, & regulations document.
6.4.4.5 Observatory Operations – Phase 2

Successful proposals that have been allocated and approved time and resources on the SKA Observatory and SKA regional centres become projects. As projects, they become the containers for all pertinent information related to them including, *inter alia*, scheduling blocks, observing logs, quality assessment (QA) records, project progress against allocation, associated calibrations, faults encountered and the environmental conditions during observations. There will also be a record of communications, primarily via a ticketing/messaging system, to and from the PI and SKA staff regarding the project. Any communication outside of the ticketing system should be recorded as a note in the project by the appropriate SKA staff member.

Phase 2 of observatory operations is traditionally related to those functions pertinent to projects and preparing them for execution. This includes the detailed design of the observations through to their scheduling and execution on the telescope, as illustrated in Figure 14.
6.4.4.5.1 Observation Design

Scheduling blocks are initially generated through the automated extraction of the relevant technical details from the original proposal. The PI, or their designate(s), can if necessary or required (e.g., by the TAC), further develop the detailed instrument and telescope configurations for each SB in their project. Similar to proposal preparation (§6.4.4.4.1), PIs will be able to select from a library of templates to refine their observation designs if needed, permissible or appropriate.

As well as a detailed prescription of the instrument and telescope configurations, the PI will also be able to specify how the data will be processed by selecting the data reduction workflow(s) that will be associated with the observed data.

Note that it is expected that PIs will carry out the majority of the observation design for their projects during proposal preparation with help from support staff as and when it is required. It is anticipated that the required level of support for this will decrease over time as the SKA community become familiar with SKA science operations, including the observation preparation and design tools.

PIs will be required to complete their observation designs at least by the start of the new observing cycle. This is so that an incomplete observing database can be avoided for the start of the observing cycle. In addition, the sooner SBs are included in observation planning the more likely those projects will be executed. Observation design of projects will be possible throughout the observing cycle, but these are expected to be minor adjustments and should not consider sizable reworks of the observation design that would change the observation planning.

6.4.4.5.2 Observation Planning

For observation planning to proceed, SBs need to be available in the observation data archive (ODA). Observation planning for each telescope can then be executed considering all known constraints. These can include any scheduled maintenance or commissioning work, observations that need to be observed contemporaneously between the two SKA telescopes, or other known scheduling constraints (e.g., coordinated observations with other facilities). Clearly, the observability of targets in the sky is another constraint. Observation planning can be exercised over any user-defined timescale.

The scheduling priorities of SBs that emerge from observation planning are driven by the scientific priority assigned by the proposal review process. Scheduling priorities are generated from these for each SB based on the expected environmental and resource constraints. Scheduling priorities can be updated as determined by operational needs and priorities. Observation planning will include a simulation mode whereby operations staff can “execute” the observing programme over the planning period, look for discrepancies, errors or inefficiencies, and refine and repeat the planning process if necessary, before the resulting scheduling priorities are made available to the telescopes.

In the same way, “fake constraints” can be used to simulate an observing programme and investigate the impact to the productivity of the telescope under various scenarios; for example, losing half an array due to some unforeseen event, or for some known major engineering work that needs to be undertaken in the future. This allows the operations staff to plan appropriate remedial action. This will also be an important tool for managing and predicting the SKA members’ completion statistics.
Observation planning is an activity that necessarily reflects overall observatory-wide science priorities, members’ shares, and telescope operations. As the scheduling priorities of SBs will be dependent on a number of factors that bridge the activity across both telescopes, observation planning will be conducted at the GHQ as this provides an observatory-wide view of telescope operations. SBs and their resultant scheduling priorities are then replicated to the telescope sites where the science programme is executed according to those priorities.

The observations executed will be regularly monitored and tracked against the planned science programme, primarily by the operations team at GHQ but some oversight from the operations teams at the two SKA telescopes is also be expected. Any significant deviations can be investigated if necessary. The shift log tool will record the obvious details and reasons for deviations – e.g., weather, data quality, etc. – but it is unlikely to be obvious to the Telescope Operator that the scheduling tool has chosen an observation to execute that deviates from the original plan.

It is explicitly understood that the outputs of observation planning at GHQ will not necessarily translate to what is actually executed at the SKA telescopes. Hence, the monitoring will feedback into the next planning iteration where scheduling priorities can be adjusted to allow a finessing and moulding of the science programme.

Figure 14. Phase 2 of observatory operations. In observation design, the PI defines the details of the spectral, telescope, and data reduction parameters, including observing and calibration strategies. This generates SBs that are used for observation planning that produces the scheduling priority for each SB. At the telescope, these scheduling priorities are used to select individual SBs from which the relevant scans are then executed for the project.
6.4.4.5.3 Identifying Commensality

Commensality between SBs of different (or the same) projects will be identified during the observation planning stage. In particular, instances of data and observing commensality (see §6.4.4.2.6) will need to be identified and the SBs appropriately packaged for execution into a compound scheduling block. A Compound SB is a scheduling construct that contains a set of SBs to be executed in parallel. The SBs share the same front end (stations or dishes) resources, but not necessarily the same back end (i.e., compute) resources. The Compound SB is scheduled as a whole, but the contained scheduling blocks are executed in parallel.

The scheduling priority of the commensal group of SBs in the compound SB will be determined by the highest-ranked SB in that group. This is simply to avoid the highest-ranked project being penalised by other lower ranked projects that it happens to be commensal with. Of course, this is a boon for those lower ranked SBs in the compound SB.

6.4.4.5.4 Flexible Observing, Scheduling, and Execution

The SKAO will execute its science programme using flexible scheduling (also known as dynamic scheduling). This is a mode of operation that allows the observatory to react quickly and efficiently to changing environmental conditions, availability of resources and capabilities, and other operational or scientific needs. Flexible observing aims to drive efficiency upwards by allowing the Observatory to continue to be scientifically productive in the face of adverse circumstances (e.g., weather, faults, etc.), and to multiplex its observing programmes as much as feasibly possible. Observations will be executed according to scheduling priorities that emerge from observation planning (see §6.4.4.5.2). An automated decision is made at the “point of execution” on whether the resources and capabilities required by the next scheduled observation are available and sufficient to execute. As changes occur in real time at the telescope, science operations can continue with high efficiency if and when these constraints and/or priorities change. Flexible observing decisions are informed by:

- dish/station availability;
- availability of receiver bands and observing modes;
- data transport capacity;
- compute availability in the correlator and beamformer;
- processing capacity of the pulsar search and timing engines;
- ingest and processing capacity of the SDP;
- capacity of the VLBI buffer;
- observability of the target(s);
- environmental constraints (wind speed, ionosphere, RFI, etc.); and
- scheduling priorities of the SBs.

Telescope management for SKA1-LOW and SKA1-MID will be aware of the most up-to-date local maintenance schedule through an interface with the engineering management system (§6.4.6.11). If the observation cannot be executed within these constraints, the scheduling tool will automatically search for and select the next-highest priority SB (or compound SB) and repeat the decision-making process before sending any observation for execution (see Figure 15).
In determining whether an SB can be executed within operational constraints, the scheduling tool will be able to look forward in time. For example, if there is maintenance planned and scheduled of particular dishes/stations a few hours in the future, the scheduling tool will ensure that no scheduling blocks that require those resources shall be sent for execution.

Flexible scheduling will also allow the Observatory to quickly respond to internal or external triggers and events and change the observing schedule depending on the priority and urgency of the triggered event. Triggered projects with override status (see §6.4.4.2.3) will be executed on the telescopes as soon as possible, aborting currently executing observations if necessary. Once a scan has been executed the system will update the shift log (and thus the database) as well as the specific project and members’ completion statistics.

6.4.4.5.5 Calibration Strategy

To produce fully calibrated data products, each observation requires a set of calibration data associated with it. It is the responsibility of the Observatory to ensure that data from each SB that is observed can be processed and fully calibrated before it is made available to the PI.

To ensure this, every SB shall be associated with a calibration *schema* that describes and specifies the calibration data required for each observation. The calibration data may:

a) be included as part of the same SB as the observation;

b) have already been observed, either as part of another science observation or as an observatory calibration; or

c) be observed at some time in the future.

In the case of c), the calibrations will need to be observed within a certain time limit and will be allocated a sufficiently high priority to ensure that the calibration data are obtained within that period. The time limit will be dependent on the stability of the system, available SDP resources, as well as the type of observation and calibration, and calibration target. Setting the priority will be a task for the scheduling tool once the original SB is sent for execution. The scheduling tool (and indeed the planning...
A consequence of this policy is that it allows for calibration observations to be shared between projects, i.e., more than one SB from different projects may be associated to an observed, or future, calibration, as well as allowing SBs to use calibrators that are not visible at the same time as the science targets. This clearly will increase the observing efficiency/productivity of the SKA telescopes. The execution time for a calibration will be attributed to an Observatory calibration project rather than to the science project. As such, it is the Observatory’s responsibility to provide the appropriate calibration data for each observation, and the PI will not be required to specify these, or estimate the time for them, in their proposal. This does not preclude a PI from defining a bespoke calibration requirement/strategy in the proposal and SB, chargeable to that project.

Table 23 lists those calibrations that can be, and those that should not be, shared between different observations and projects.

Table 23: Shared and non-shared calibrations.

<table>
<thead>
<tr>
<th>Calibrations that can be shared</th>
<th>Calibrations that should not be shared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandpass</td>
<td>Complex gain</td>
</tr>
<tr>
<td>Delay</td>
<td>Reference pointing</td>
</tr>
<tr>
<td>Phase</td>
<td></td>
</tr>
<tr>
<td>Polarisation leakage</td>
<td></td>
</tr>
<tr>
<td>Amplitude</td>
<td></td>
</tr>
<tr>
<td>Antenna voltage pattern</td>
<td></td>
</tr>
<tr>
<td>Gain-elevation curve</td>
<td></td>
</tr>
</tbody>
</table>

6.4.4.5.6 Manual Operation and Control

For safety and/or engineering requirements, it will always be possible for an Operator to take manual control of the telescope, its subarrays, components, and instrumentation. Furthermore, it will be possible to secure manual control at several levels:

- by manually requesting inclusion of an engineering, or related, operation within the schedule;
- by manually editing the execution schedule to insert an automated operation at a future point in time (by either sending an SB or engineering operation for execution); or
- by performing manual low-level control of the telescope.

Other manual operation controls may be identified through the course of operating the telescopes and will be added accordingly.

6.4.4.6 Science Data Products – Phase 3

6.4.4.6.1 Observatory and Advanced Data Products

Science data products are those that have been calibrated into useful astronomical units and can be used in scientific analysis. In general, the SKA defines three types of science data products split between two categories:
Observatory Data Products (ODPs): Observation-level data products (OLDPs) are calibrated data products generated by SDP workflows and are based on data obtained from within one scheduling block.

Project-level data products (PLDPs) are calibrated data products generated by combining several, related, observation-level data products, delivering the requirements of the PI as outlined in their original proposal.

Software pipelines to generate both OLDPs and PLDPs can (and will) be specified in advance of the SB being scheduled. The Observatory is responsible for the generation of ODPs (and associated QA). Generation of ODPs will not require any interaction by the science users, and the execution of workflows to generate these will be performed by the Observatory.

Advanced Data Products (ADPs): These are the user-generated products, produced through the detailed and rigorous analysis and modelling of Observatory data products (either at the observation or project level). The generation of ADPs will usually require some level of interactive visualisation and examination of data, as well as comparison to data from other SKA observations or other facilities.

Science users are responsible for the generation of ADPs.

6.4.4.6.2 Pipelines and Data Products

Observatory data products will be generated by the SDP using workflows and pipelines specified within the SB. The complete list of ODPs that SDP will be capable of producing is reproduced below. Each of these will have associated data processing and quality assessment (QA) information included in a log file.

Image Products 1: Image Cubes
- Imaging data for continuum, as cleaned restored Taylor term images (no image products for slow transient detection have been specified – maps are made, searched, and discarded).
- Residual image (i.e., residuals after applying CLEAN) in continuum.
- Clean component image (or a table, which could be smaller).
- Spectral line cube after (optional) continuum subtraction.
- Residual spectral line image (i.e., residuals after applying CLEAN).
- Representative point spread function for observations (cut-out, small in size compared to the field of view (FOV)).

Image Products 2: uv Grids
- Calibrated visibilities gridded at the spatial and frequency resolution required by the experiment. One grid per facet (so this grid is the FFT of the dirty map of each facet).
- Accumulated weights for each uv cell in each grid (without additional weighting applied).
<table>
<thead>
<tr>
<th><strong>Calibrated Visibilities</strong></th>
<th>Calibrated visibility data and direction-dependent calibration information, with time and frequency averaging performed as requested.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LSM Catalogue</strong></td>
<td>Catalogue of a subset of the Global Sky Model (GSM) containing the sources relevant for the data being processed. These are the sources in the FOV, as well as, potentially, strong sources outside of the current FOV. Initially, the Local Sky Model (LSM) is filled from the GSM. During data processing, the sources found in the images are added to the LSM. The resultant LSM might be superior to the GSM (not just to account for variability, but possibly also because of the addition of longer baselines, for example) and can be used as a starting LSM for future observations of the same field.</td>
</tr>
<tr>
<td><strong>Imaging Transient Source Catalogue</strong></td>
<td>Time-ordered catalogue of candidate transient objects pertaining to each detection alert from the real-time, fast imaging pipeline.</td>
</tr>
<tr>
<td><strong>Pulsar Timing Solutions</strong></td>
<td>For each observed pulsar, the output data from the pulsar timing section will include the original input data as well as averaged versions of these data products (either averaged in polarisation, frequency, or time) in PSRFITS format. The arrival time of the pulse. The residuals from the current best-fit timing model for the pulsar.</td>
</tr>
<tr>
<td><strong>Transient Buffer Data</strong></td>
<td>Voltage data passed through from the CSP when the transient buffer is triggered.</td>
</tr>
<tr>
<td><strong>Sieved Pulsar and Transient Candidates</strong></td>
<td>A data cube which will be folded and de-dispersed at the best dispersion measure, period and period derivative determined from the search. A single ranked list of non-imaging transient candidates from each SB. For those transients deemed of sufficient interest, the associated “filterbank” data will also be archived. A set of diagnostics/heuristics that will include metadata associated with the scheduling block and observation. Discovery of sufficiently interesting pulsars will generate an alert as well as being recorded in a log.</td>
</tr>
<tr>
<td><strong>Science Alerts Catalogue</strong></td>
<td>Catalogue of science alerts produced and communicated by the SDP. The alerts themselves are IVOA alerts. This catalogue provides a searchable and retrievable record of past alerts.</td>
</tr>
<tr>
<td><strong>Science Product Catalogue</strong></td>
<td>A database relating to all science data products processed by the SDP. It includes associated scientific metadata that can be queried and searched and includes all information so that the result of a query can lead to the delivery of data.</td>
</tr>
</tbody>
</table>

Multiple different data products can be produced commensally. These, and the processing parameters required to generate them are specified in the SB ahead of time. There is no user interaction within the SDP, but users will be able to set parameters (through SKA staff) when their successful proposal is turned into SBs (which contain definitions of “processing blocks”).

Consideration of the overall SDP processing load required for the generation of all products associated with a particular SB will be needed at the time of proposal assessment (as part of technical feasibility), but also at the project planning stage and as the SB is scheduled.
There are however always going to be corner cases - some of which might be covered by enabling a test observation as part of a proposal (with a feedback loop involving science users to adjust SDP pipeline parameters before going “full steam ahead”), or by producing multiple data products (using a family of different clean boxes, etc.) whilst the visibility data are still available.

Delivery of raw visibility data as a data product (with or without averaging and/or calibration) is technically possible and is likely to be necessary while the development of robust calibration pipelines continues in early operations. However, in steady-state operations, the Observatory is responsible for the delivery of calibrated data products and proposals requesting raw visibility data are expected to be very much the exception and will require a detailed plan for calibration and the generation of data products.

6.4.4.6.3 Quality Assessment

Quality assessment (QA) occurs within each element of the observatory that undertakes data processing – principally in the SDP but also in the CSP (specifically in the PSS and PST) and the LFAA Monitoring, Control and Calibration System (MCCS).

Within the SDP, quality assessment is undertaken as part of the real-time and offline processing pipelines. Its purpose is to check whether the observations are proceeding or have proceeded as planned. In the real-time case, QA can give useful feedback that might affect whether the current SB should be continued or aborted (e.g., from the impact of the ionosphere on the data), and in the offline case measure the performance of the telescope system and determine whether the SDP pipelines themselves are appropriately tuned.

SDP QA will be performed on:

- data astrometry (source positions);
- photometry (comparison of source fluxes with known standards);
- radiometry (overall image statistics);
- polarimetry (comparison of polarisation fluxes and angles with known standards); and
- spectrometry (measurement and characterisation of emission line fluxes and moments).

The PSS and PST facilities within the CSP will produce QA artefacts as timing data are passed through the various analysis algorithms. The LFAA MCCS servers will have access to station-level calibration and monitoring data, so can report on station health and calibration solution behaviour. Details of the specific metrics are TBD.

In all cases, QA information is passed to TM. Aggregated information will be entered into a QA log that is preserved and delivered with (and linked to) the ODPs, and stored in the project log, ensuring that it is accessible to the operations staff at the Observatory and to science users. The non-aggregated, live system health information will be accessible to SKAO Operators and staff.

In some instances when a dataset fails QA, it will be operationally important to retain the visibilities for investigation by SKAO staff. The capacity to save, investigate and potentially reprocess these data will be dependent on the available buffer capacity and SDP resources. Such investigations may uncover issues with the telescopes themselves, or highlight a deficiency in the relevant SDP pipeline, and therefore prevent further data from failing QA in the same manner.
6.4.4.6.4 Lifecycle of Data Products

Observatory data products, i.e., those generated within each SDP, will be delivered to SKA regional centres where users will access them (§6.4.5). Once all planned SDP pipelines needing a particular set of raw data have been completed, those data can be deleted when necessary to free space in the SDP’s buffer. This applies to the hot buffer, where data are stored only whilst batch processing is being run and from which an almost immediate deletion of raw data is anticipated once a batch pipeline completes, and to the cold buffer.

Deletion of unprocessed data from the cold buffer is also possible and might be required if the buffer has insufficient space to take in data from a ToO observation that has been triggered with override status. In that case, data will be deleted in accordance with their differing science prioritisation values, with the most valuable data deleted last.

In addition to being delivered to SRCs, all ODPs will be stored in a long-term preservation system for both telescopes. This long-term preservation is capable of restoring data products to SRCs but should be seen as an option of last resort since this storage will be off-line and slow to extract data from (so that it is as inexpensive as possible). Requests to restore data from the SDP long-term preservation system will come from SRCs to the Observatory, not directly from individual users. Note that there are no direct interfaces to the SDP for non-staff users. If a user discovers that some of their data is missing, they can then file a Helpdesk ticket (§6.4.10.1) and the data product will be re-delivered to the SRCs, if necessary. For the majority of cases where data products are lost from an SRC, it will be faster and more efficient to copy missing products from another SRC than to use the observatory’s staging and delivery platform and data link (which will be needed for ongoing campaigns).

Once delivered to the SRCs, users will be able to access these data products if they have appropriate permissions. As products move out of their proprietary periods, user access will be opened up to the general public. Some products may be public from the outset.

The timescales for data to make its way through the SDP and into SRCs are relevant to mention here. Execution of a SKA project may take anything from minutes to months, depending on the length of each scheduling block instance, the number of different scheduling blocks required and any special weather or observational conditions they may need. For each scheduling block instance actually executed, the SDP will ingest data and work on initial pipelines in real-time, but thereafter data is placed into a “cold” buffer for storage until the bulk SDP processing, generating the observation-level data products can occur - this will depend on the loading of the SDP. For example, the most challenging processing, resulting from a long (e.g., 10 hour) SB, may take several times longer than the SB duration to be processed by the SDP, thus data processing will sit in a queue, with the next-most-pressing processing selected once the SDP batch processing system next finishes its current work. This means that it might take up to 1-2 weeks after SB execution for observation-level data products to be generated by the SDP. Once OLDPs are created by the SDP they will be queued for delivery to the SRC network. Again, this process is a bottleneck that depends on the available bandwidth, so further delays in delivery are possible and should be expected if high-data projects are undertaken. (The metric to bear in mind here is that the anticipated connectivity of the SDP into the SRC network is 100 Gbit/s, or ~1 petabyte per day. Capacity on this link is a resource that will need to be planned for alongside the SRC storage and compute capabilities.) It is possible to foresee delays of order 1-2 weeks in the delivery of OLDPs to SRCs, but this is an area that will need to be prototyped extensively, and timescales analysed, during the construction and science verification periods.

At the point where OLDPs are in the SRC network, it should be possible to give users access to them in that form, but the full project-level data products which are generated by SKA using SRC resources can only be created after all necessary OLDPs are in place. It will be important that the required role
of SRC staff in the development of PLDPs introduces the smallest possible delay at this stage, and that user expectations on these timescales are well managed, as they will be the last hurdle before users can access PLDPs.

6.4.4.7 Science Operations Workflow

The SKA science operations workflow starts with the submission of a proposal and ends with users accessing data products in SKA regional centres around the world (Figure 16). The SKA Observatory first engages with its community through the issue of a call for proposals and then with proposal preparation (§6.4.4.4.1). Successful proposals then enter the workflow as SKA projects. Observation design (§6.4.4.5.1) ensures that the SBs for each project are sufficiently well defined such that users’ only interaction with the SKA thereafter is after the resultant ODPs have been delivered to the collaborative network of SRCs (§6.4.5).

All relevant observational details pertaining to SKA observing projects are kept within the Observatory data archive (ODA), including the SBs. Observation planning (§6.4.4.5.2) will take SBs from each project and given the set of known constraints, which includes maintenance schedules for each telescope, the science priorities for each project to emerge from the proposal review process, and the requirement to provide a return for the members of the SKA Observatory, and maps out the science programme to observe. Scheduling priorities are assigned to each SB in the ODA over a given timeframe, which could be the whole observing cycle. Commensality between SBs is also identified at this stage and the corresponding SBs packaged into a compound SB (§6.4.4.5.3).

The ODA is replicated between the three Observatory sites, allowing the scheduling priorities to be used by telescope management at the SKA1-LOW and SKA1-MID telescope sites to guide and execute the observing programme in a flexible manner. The availability of telescope resources and capabilities, constrained by short-term engineering schedules and environmental conditions, inform whether any single SB can be expected to be feasibly executed. Each telescope will adapt its schedule flexibly in response to any perturbing events that are triggered during the observing period, e.g., ToO events or faults that interrupt observing (§6.4.4.5.4). VO alerts may originate either internally or externally14 to the Observatory (see §6.4.4.2.3). In this way, telescope management ensures that only SBs that will result in ODPs will enter the signal chain (blue arrows in Figure 16).

As completion statistics are incremented (with each observed SB), this and other factors will influence the priority of remaining SBs when scheduling priorities are updated by the next iteration of observation planning (which can, in principle, be carried out at any time). The likely operating model is for scheduling priorities to be updated on a regular basis, e.g., every 2–3 days, informed with the most up-to-date information from across both SKA telescopes. The revised scheduling priorities for each SB are updated in the ODA and replicated to the telescope sites with minimum delay (the actual latency will depend on the database technology chosen), ensuring that observing continues seamlessly. In the event of a delay in receiving updated scheduling priorities, or some unforeseen circumstance leading to loss of network communications, the SKA telescopes will be able to continue observing independently of GHQ, for the whole observing cycle if necessary, following their most up-to-date list of SB scheduling priorities.

Throughout, the systems are monitored for faults and alerts by the local monitoring & control network of computers, and the quality of the data is automatically assessed by the data reduction pipelines. A fundamental role of the data processing systems, and the SDP in particular, is to perform sufficient

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14 Some external triggers, that are not associated with an existing project, may come in as a direct request to the Observatory (most likely at the GHQ). If approved by the DG (or their delegate), SKA staff can quickly create a project and SBs, and allocate a priority for immediate execution at the telescopes.
calibration of the raw data to allow output data products with much reduced average data rates – with a decrease in the average data rate from approximately 10 Tbit/s to around 100 Gbit/s. Note that for the SKA, data reduction is an integral part of the observing workflow. If the SDP ingest is not available for any length of time, data acquisition will also cease, and observations will need to be aborted and repeated.

The fault and QA statuses for each observation are recorded and logged by the shift log tool. Any action taken in response to these, or any other alert or warning, should also be recorded in the shift log.

If the data quality falls below (or above) certain thresholds, then the Operator is informed (together with the relevant detail) with the shift and project logs updated. The Operator may decide to continue or repeat the SB depending on the severity of any problem encountered. If the QA indicates failure at the start of execution of an SB, then it may best to immediately abort/repeat/restart the observation (if it is safe to do so). If QA indicates a problem that is not discovered until well through the execution of an SB, then it is probably better to abort and repeat the SB at a later date after some investigation has been undertaken to understand and rectify the problem. If the observation fails and the reason and resolution to the issue are not immediately apparent, then the Operator will move on to the next

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Figure 16. Science operations workflow for the SKA Observatory showing the flow of information (proposals and schedules), processes (project management, observation planning, telescope management, monitoring, and control), and data.
SB and submit a ticket describing the fault for future investigation. The link to this ticket is automatically added to the shift log.

6.4.4.8 Science Operations Role Descriptions and Staffing Levels

Table 24 shows the roles and an estimate of the number of science operations staff required to deliver the model described above. Note that the science operations staff are supported by admin and IT staff not represented in this table.

Table 24: Roles, location, and number of staff to support the science operations of the SKA Observatory.

<table>
<thead>
<tr>
<th>Role</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Director of Operations</td>
<td>GHQ</td>
<td>To lead and manage the operations group and provide operational policy direction for the SKA Observatory.</td>
<td>1</td>
</tr>
<tr>
<td>Admin Support</td>
<td>GHQ</td>
<td>To support the activities of the operations group at the GHQ</td>
<td>1</td>
</tr>
<tr>
<td>Head of Science Operations</td>
<td>GHQ</td>
<td>To lead and manage the science operations group and provide direction for science operations activities at the GHQ.</td>
<td>1</td>
</tr>
<tr>
<td>Operations Scientists</td>
<td>GHQ</td>
<td>To provide support to observing programmes and provide expert scientific domain knowledge in specific areas of science operations (e.g., imaging, VLBI, calibration). User support. Data analysis.</td>
<td>6</td>
</tr>
<tr>
<td>Proposal Management and Scheduling</td>
<td>GHQ</td>
<td>To generate and model observing plans, establishing observing priorities for projects. To support the time allocation process with cycle planning.</td>
<td>2</td>
</tr>
<tr>
<td>SKA Helpdesk</td>
<td>GHQ</td>
<td>To manage and support the SKA Helpdesk system. Triage tickets not automatically directed to pre-assigned “departments”. Provide reporting and metrics of Helpdesk usage.</td>
<td>1</td>
</tr>
<tr>
<td>SRC Project Scientist</td>
<td>GHQ</td>
<td>To lead and manage the SRC activities within the science operations group. Liaise with the ensemble of SRCs to ensure data access to SKA users, and lead on ensuring the required level of computing support required is provided in the SRC network. Support the Head of Science Operations and Director of Operations in management activities related to SRCs.</td>
<td>1</td>
</tr>
<tr>
<td>SRC Scientists</td>
<td>GHQ</td>
<td>Model, maintain and develop techniques for the management of SKA science data products distributed to a distributed global network of SRCs. Maintain and continue development of SKA science gateway for SKA users. Maintain location database of science data products across the global network of SRCs.</td>
<td>4</td>
</tr>
<tr>
<td>Performance and Quality Manager</td>
<td>GHQ</td>
<td>Establish and manage the performance and data quality processes. Management of data analysts. Track Observatory performance against stated KPIs.</td>
<td>1</td>
</tr>
<tr>
<td>Data Analysts</td>
<td>GHQ</td>
<td>Monitoring QA logs and perform trend analysis of data quality. Maintain and develop dashboards for tracking efficiency of SKA Observatory against stated KPIs.</td>
<td>3</td>
</tr>
<tr>
<td>Role</td>
<td>Location</td>
<td>Description</td>
<td>Number</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>SAFe Product Managers</td>
<td>GHQ</td>
<td>Product managers for software development in support of present and future science operations in observation management, telescope control, pulsar astronomy software, and data processing. The scientists responsible for defining the priorities for release development while maintaining the overall system integrity. Responsible for accepting work as done.</td>
<td>4</td>
</tr>
<tr>
<td>Telescope Director</td>
<td>AUS</td>
<td>To lead and manage all activities of the SKA1-LOW telescope. Represent the SKA Observatory to host country authorities.</td>
<td>1</td>
</tr>
<tr>
<td>Deputy Telescope Director</td>
<td>AUS</td>
<td>Works closely with the Telescope Director in providing effective management of the operations of the SKA1-LOW telescope.</td>
<td>1</td>
</tr>
<tr>
<td>Admin Support</td>
<td>AUS</td>
<td>Support the activities of the operations group at the SKA1-LOW telescope.</td>
<td>1</td>
</tr>
<tr>
<td>Head of Science Operations</td>
<td>AUS</td>
<td>Lead and manage the science operations group and provide direction for science operations activities at the SKA1-LOW telescope.</td>
<td>1</td>
</tr>
<tr>
<td>Operations Scientists</td>
<td>AUS</td>
<td>Provide support to observing programmes. Act as astronomer-on-duty during observing shifts. User support. Data analysis. Provide expert scientific domain knowledge.</td>
<td>10</td>
</tr>
<tr>
<td>Data Analysts</td>
<td>AUS</td>
<td>Monitoring QA logs and perform trend analysis of data quality. Data reduction and analysis, including generating OLDPs from PLDPs (see §6.4.4.6.1).</td>
<td>6</td>
</tr>
<tr>
<td>Telescope Operators</td>
<td>AUS</td>
<td>Operation of the SKA1-LOW telescope. Monitor progress of the observing schedule and the execution of science programme.</td>
<td>6</td>
</tr>
<tr>
<td><strong>GHQ TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>25</strong></td>
</tr>
<tr>
<td>Telescope Director</td>
<td>RSA</td>
<td>To lead and manage all activities of the SKA1-MID telescope. Represent the SKA Observatory to host country authorities.</td>
<td>1</td>
</tr>
<tr>
<td>Deputy Telescope Director</td>
<td>RSA</td>
<td>Works closely with the Telescope Director in providing effective management of the operations of the SKA1-MID telescope.</td>
<td>1</td>
</tr>
<tr>
<td>Admin Support</td>
<td>RSA</td>
<td>To support the activities of the operations group at the SKA1-MID telescope.</td>
<td>1</td>
</tr>
<tr>
<td>Head of Science Operations</td>
<td>RSA</td>
<td>To lead and manage the science operations group and provide direction for science operations activities at the SKA1-MID telescope.</td>
<td>1</td>
</tr>
<tr>
<td>Operations Scientists</td>
<td>RSA</td>
<td>To provide support to observing programmes. Act as astronomer-on-Duty during observing shifts. User support. Data analysis. Provide expert scientific domain knowledge.</td>
<td>10</td>
</tr>
<tr>
<td>Data Analysts</td>
<td>RSA</td>
<td>Monitoring QA logs and trend analysis of data quality. Data reduction and analysis, including generating OLDPs from PLDPs (see §6.4.4.6.1).</td>
<td>6</td>
</tr>
<tr>
<td><strong>SKA1-LOW TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>26</strong></td>
</tr>
<tr>
<td><strong>Observatory Operations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Regular communication lines between the operations groups at the three sites will be maintained via an operations coordination group, composed of the heads of science and engineering operations, and the Deputy Telescope Directors, meeting at least once each month (TBD). This coordination group is important for the successful operations of the Observatory and its telescopes. Each individual operations group, at the telescopes and GHQ, will themselves have frequent (at least weekly) meetings to discuss ongoing operations (planning/observing/processing/maintenance, new and old faults). These meetings will have representation from the main observatory functions (maintenance, science, computing, software).

6.4.4.8.1 Telescope Operators and Data Analysts

Table 24 shows that there will be 6 FTE to cover the Telescope Operator function for each SKA telescope. The Telescope Operators will monitor and control each SKA telescope from the science operations centre in Perth and Cape Town, for SKA1-LOW and SKA1-MID respectively – no travel to the site is necessary. Taking this into consideration, simple modelling shows that 6 FTE is sufficient to cover three 8-hour shifts in a day over an observing cycle. This allows for leave and other absences.

However, the Telescope Operator role will be shared with the duties of the data analysts (i.e., each Telescope Operator will also be a data analyst), thus providing increased flexibility with at least 12 staff to cover the operator shifts. This will ensure that, with good management of working schedules, there will always be staff available to provide 24/7 coverage for operating each telescope.

6.4.4.9 Science Group Role Descriptions and Staffing Levels

Here we provide the estimated staffing levels and role descriptions for the science group of the SKA Observatory. The key function of the science group is to champion and safeguard the scientific capabilities and accomplishments of the SKA Observatory. The responsibilities include engaging and communicating effectively with the scientific user community within current and prospective member countries.

The scientific interests and priorities of the community are channelled into the SKAO design and potential future upgrades, as well as the use of the facility. The science group have responsibility for the coordination and formulation of science input and priorities for the SKA Observatory development plan (as outlined in §6.1.1) and the development roadmap (through consultation/community workshops with the science community, the relevant advisory bodies and the member countries). The currently foreseen capabilities and upgrade opportunities are communicated back to the user community, so they remain optimally informed and engaged.

The scientific capabilities of the SKA telescopes are safeguarded through close involvement with the scientific commissioning of newly deployed equipment. The responsibilities include maximising the overall scientific return of the Observatory within the constraints of the agreed access policy. This is accomplished via a suitable peer review of submitted observing proposals prior to making recommendations for time allocation as well as the periodic progress review of any long-term allocations of observing time. Tracking the scientific return of allocated observing time will include tracking of relevant publications and their citation impact. The science group is located at the GHQ.
Table 25: Role descriptions and number of staff required to support the science activities of the SKA Observatory.

<table>
<thead>
<tr>
<th>Role</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science Director</td>
<td>GHQ</td>
<td>To lead and manage the science group and provide science policy direction for the SKA Observatory. Lead the proposal review process.</td>
<td>1</td>
</tr>
<tr>
<td>Project Scientists &amp; Scientists</td>
<td>GHQ</td>
<td>To provide scientific domain expertise that is of relevance to the SKA Observatory in support of future instrumentation upgrades and undertake an independent research programme. Coordinate and manage the proposal review process.</td>
<td>6</td>
</tr>
<tr>
<td>Post-doctoral fellows</td>
<td>GHQ &amp; SOCs</td>
<td>To undertake independent research programmes that make effective use of the SKA Telescopes.</td>
<td>6</td>
</tr>
<tr>
<td>Time Allocation Support</td>
<td>GHQ</td>
<td>To support the observing proposal call, peer review and time allocation activities at the GHQ.</td>
<td>1</td>
</tr>
<tr>
<td>Admin Support</td>
<td>GHQ</td>
<td>To support the activities of the science group at the GHQ.</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>15</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6.4.5 SKA Regional Centres

There is a well-recognised need to have a network of regional or national computer and data infrastructures giving users access to SKA’s data products and to the tools and capabilities needed to interact with and analyse these data products. These are referred to as SKA regional centres (SRCs). In this section, the SRCs are described from the SKAO perspective. The SRC steering committee’s white paper provides a complementary view [RD24]. The two are broadly consistent and are very much informed by the work of the SRC steering committee members, who include two senior SKAO operations staff. Further development of the design and plan for implementation of the network is underway under the guidance of the SRCSC, with a number of working groups being established. SKA has also added the role of SRC architect to the staffing plan, and this role will work with the SRC representatives to develop the design for the SRC network, providing a substantial, dedicated resource to assist this critical effort. The SKAO will work with the SRC steering committee to implement an independent review of the SRC design once that design is at a sufficient state of maturity.

The SRCs are logical and/or physical centres through which users will interact with the SKA ODPs. The existence of SRCs is required both by SKA and by the users. They are operationally critical as part of the data flow from SKA to users and they are mission-critical for the delivery of science results from SKA data.

Here the major functions provided by the global network of SRCs are outlined, split into those SKA-facing functions towards which SKA will play an operational role, and user-facing functions that are more decoupled from SKA operations, but which are still essential and will be tracked.
SKA facing functions:

Data Ingestion

SKA must be confident that science data products generated within each SDP can be interrogated by users without impacting the operation of the SDPs themselves – that is to say, users will not have access to the SDPs, since these are a fundamental and schedulable part of each SKA telescope. The Observatory must be confident when scheduling a particular SB that the capability to ingest the data products is available somewhere across the SRC network and that there is sufficient data network bandwidth available to actually perform the transfers. This is because the space in the data staging area of the SDPs is also limited, and it would be very inefficient (and slow) to need to copy data out of the SDP’s long term preservation systems rather than transferring data products whilst they still reside in the relatively fast data staging area of the SDP’s data buffer. Ultimately, if an SRC cannot be identified as able to receive SKA data products as they are created in the SDP, there could be scheduling constraints imposed on the telescopes themselves.

Project-level Data Product Generation

Many projects will require only one SB to complete or will have SBs that can be interpreted independently of other SBs. But other projects need, for example, deep images or stitched mosaics that require multiple SBs’ data to be combined. Workflows required to generate the project-level data products which enable the observational goals set out in the proposal can be well-defined in advance, with estimates of the hardware resources needed to perform them. We anticipate that these workflows (e.g., combining overlapping images into a mosaic or combining multiple data from the same field to get to the required depth) will be carried out in SRCs, by SKA Observatory staff (in liaison with science users). This will be done using software pipelines that the SKA Observatory develops and is responsible for. This is important to ensure data product integrity and traceability and for SKAO to be able to declare a project successfully complete. For example, if the Observatory gives time to a project requiring an image cube of sensitivity equivalent to 100hrs, then the SKAO has a responsibility to ensure that after committing telescope resources to collect the data, images of the appropriate depth and quality are indeed created and made available to authorised users in a timely manner. (This does not imply that the Observatory would guarantee a particular sensitivity, but rather that it would guarantee that the data processing used passes QA.)

There is also a suite of functions required in order to enable the SRCs to share the burden of storing data products and providing archive resources and supporting users for which collaboration between the SRCs can greatly increase overall efficiency and reduce cost. SKAO anticipates performing a coordinating, operational role in the day-to-day work needed to manage the network of SRCs, in collaboration with colleagues employed at SRCs (through the SRC operations group – see §6.4.5.4).

Data Indexing and Management

The SKA and SRCs must have visibility of the location of each copy of SKA data products and allow a centralised data management service to manage these copies as required.

SRC Performance Tracking

Checking SRCs are available to perform compute requests and tracking delivered capabilities against those pledged.
Network Health Monitoring
Checking the health and performance of the network and fault reporting.

SRC Common Software Management
To coordinate the development and deployment of shared software across the SRCs, and software to support SRC-collaboration activities.

In addition to the SKA-facing functions, SRCs will provide users with capabilities to perform their science analyses which are essential to delivering scientific return. Although the immediate scientific return of SKA is in the provision of users with the data products they need to enable the science cases as described in their observing proposals, it must be recognised that in the long term it is expected that at least as much science impact will come from the re-use of SKA data products after they become public. So, the term "user" here includes not only those PI/KSP teams with active SKA projects but also astronomers making use of public SKA data.

User-facing functions:

Provision of a Science Analysis Platform
SRCs will serve as analysis facilities for users, enabling them to develop and run science analysis workflows, and generate advanced data products, on computing platform(s) provided in the SRC ecosystem. This ecosystem will need to include ways for users to collaborate on shared projects, to save their workflows and preserve data and software provenance information, to have access both to interactive compute sessions on appropriate (possibly very large) scale resources, and to submit offline jobs.

Indexing of New Data Products
Include all SKA science data products (observation-level, project-level and advanced (user-generated) data products) in an index of data products that can be accessed by search tools.

Data Search Functionality
Allow users to search for and extract public SKA data products, including supporting external query requests (e.g., via IVOA protocols).

Helpdesk Provision
Problem-solving and user support.

User Support
For pipeline development (possibly via the Helpdesk, but specifically providing data processing expertise to SRC users developing analysis pipelines to make use of SKA data).

Authentication
SRCs must enable registered SKA users to use their SKA credentials for SRC activities, and support data access according to SKA data access policy.

SRCs will provide core functions to the Observatory and the SKA user community, but the SRCs are expected to differ from region to region in terms of the set of functions each SRC chooses to provide, based on their individual and specific business cases.

The Observatory will deliver ODPs to the SRCs from each SDP, buffered to remain within the capacity of the long-haul data links. Individual SRCs may be subscribed in advance, or allocated as part of the proposal review process, to receive data products from specific projects in order to plan for efficient use of each SRC. Copies of all the ODPs will reside in the Observatory’s long-term storage. However, it will be exclusively through the SRC interface that SKA users will access SKA data products (Figure 17).
6.4.5.1 Roles and Responsibilities

In Figure 18, a ‘swimlane’ diagram is used to show where the responsibilities of the Observatory, the SRC network, and the SKA user (whether as a PI/CoI, or an archive user) lie with respect to delivering the SKA science programme. It shows two phases: the project execution phase and the science extraction phase. The Observatory is responsible for the project execution phase, which includes the generation, calibration, and delivery of OLDPs and PLDPs into the SRC network. The SRCs are then responsible for supporting the SKA community of users in extracting the science from the ODPs delivered to them for publication and dissemination.

The science extraction phase will generally result in further, more advanced data products (ADPs, see §6.4.4.6.1) to be generated as a consequence of the advanced analysis and modelling techniques that will be employed by the science community. Those ADPs that will appear in publications by the PI, or that will be made public, will be added to the SKA science archive and made available to all users (while respecting the appropriate proprietary access periods). This will raise efficiency in the SRCs by avoiding repetition of the processing.

6.4.5.2 SKAO and User Responsibilities for Software and Pipelines

The boundary between SKAO’s responsibility for data products and the users’ responsibility requires striking a balance between centralisation and the desire for SW quality and data traceability, and the ability to declare that the Observatory’s responsibilities to a specific PI or KSP team have been achieved, against the somewhat competing need to encourage scientific freedom and innovation.

As the figure shows, the SKA has responsibility for data product generation up to the project level. However, though maintaining and running the software pipelines to generate the PLDPs from OLDPs will be the responsibility of the Observatory, the actual processing to generate these (for the projects that need it) will be undertaken within the SRCs. This is a core SKAO-facing function that the SRC network will provide. This extension of PLDP creation on top of SDP’s OLDP generation is a relatively small change – it allows the Observatory to perform QA metrics on more complete data products, and of course, feedback difficulties and failures immediately to affect pipelines not just for combining OLDPs but also for their creation in the SDP. Since all PLDPs are in any case already delivered to the
SRCs, users will also have access to those data products if they wish to combine OLDPs in other ways. This has the effect of reducing risk by bringing responsibility for PLDP generation within the SKAO’s remit, without reducing opportunities for scientific innovation.

Figure 18. Swimlane diagram showing the responsibilities for the generation of science data products during the project execution and science extraction phases of a science project. The left lane depicts the Observatory’s responsibilities, the middle lane those of the SRCs, and the right lane for the PIs and Co-Is of SKA projects and general archive users. Observation-Level and project-level data products are generated by the Observatory, while advanced data products are produced by users at the SRCs.

### 6.4.5.3 Data Management Model for SKAO and SRCs

SKAO will generate observation-level data products in the SDPs. Once these are delivered to the SRCs the SDP sites will store copies of them in the long term preservation (LTP) system, a high-latency data storage system existing only as a backup of the data products so that that can be re-delivered to SRCs if all copies in the SRC network are lost. In other words, the LTP system is a back-up of last resort and not an actively managed storage element in the network of SRCs. SKA has a responsibility to ensure that data products are preserved, forever, in the LTP which is independent of SRC activity – so for example, it will not be possible to delete items from the LTP on the grounds that there are copies in place in one or more SRCs.

Within the SRCs the management of data products can be more flexible. By agreeing to share the burden of data storage and access to users, SRCs can provide coverage of the whole SKA archive of Observatory and advanced data products without requiring that each SRC must keep a full (and fully backed-up) copy of each data product. Instead, there can be a global data management service that applies rules to data products or collections of data products and manages data transfer between SRCs.
in order to maintain adherence to the rules. The service can tag “spare” copies of data products for deletion (without necessarily performing the deletion) so that individual SRCs can clear space when resources become limited.

Using a global data management service to perform this function is essential to avoid confusion – SKAO’s role in this will be to provide coordination (through operations group personnel, see §6.4.4.8) and the necessary software to run the data management service as well as the hardware (e.g., servers) to maintain the catalogue of data product locations.

### 6.4.5.4 Operational Considerations

An operational SRC network must be able to continuously maintain both SKA- and user-facing functions – this means being ready to accept data pushed from the SKA Observatory which will allow SKAO to complete the data processing to provide project-level data products. This will also allow the subsequent enabling of the users themselves to log into the systems and be given authenticated access to the data and computing resources they need to pursue their science analyses.

Several areas of management are needed on various timescales. An SRC coordination committee (SCC), with representatives from each SRC and the SKAO, will work together to:

**Annually**

- Oversee the pledging of SRC resources (see §6.4.5.5) into the SKA-facing roles and for user-facing purposes. Interaction between the SCC and the SKA’s resource allocation process will be required to ensure sufficient capacity to support the next cycle’s science programme.
- Manage a roadmap for the development of SRC-related technologies and pledging of (human) resources to enable this – for example, SRC collaboration tools, data management and transfer tools, improving best practice.

**Ongoing**

- Develop and maintain a long-term roadmap for altering data transfer, data storage, and data processing capabilities of the SRC network in line with the prospective long-term science programmes of the SKA Observatory.

**Quarterly**

- Agree on priorities in development areas for subcommittees to work on.
- Track performance of SRCs against pledges, both for SKA-facing and user-facing activities and of the data transfer network links.
- Review data management policies to ensure appropriate quality of service (trading off performance and cost/capacity needs).

The SCC will be supported by an operations team of SKA and SRC staff, the SRC operations group (SOG), to implement the policies and priorities that have been agreed and provide the required monitoring and reporting capabilities to alert stakeholders to any difficulties. The SOG will ensure the continuous availability of the SRC network by:

- reporting to SCC the performance of SRCs against pledges, both for SKA-facing and user-facing activities and on the performance of the data transfer network links;
- updating data management policies to ensure appropriate quality of service (trading off performance and cost/capacity needs);
- maintaining a global data management service implementing the data management policies;
- monitoring the ability of each site storage element to accept data products from SKA sites;
- monitoring the ability of appropriate sites to accept batch processing jobs and to provide interactive sessions for users; and
monitoring the network link availability and performance (e.g., through continuous monitoring of links in use and liaison with network providers).

The SOG will report any problems to the SRCs concerned through a formal ticketing system. It will be the responsibility of each SRC to perform its own internal operational procedures to ensure its availability to the SRC network is in agreement with the terms in its MoU with the SKAO and the terms and conditions of its accreditation as an SRC.

The SRC operations group will manage the delivery of ODPs into the managed data storage in the SRC network to specific SRC sites.

6.4.5.5 Building a Collaborative SRC Network: Pledging and Accounting

At the time of writing, a model for how SRCs will be operated and governed is under active development. There is good agreement that pledges of resources, and not financial contributions, should be put forward by representative agencies from member countries to support SRC efforts.

In the current model, there will be an SRC coordination committee (SCC), comprising representatives from the SKA Observatory and each member state. The SCC will be responsible both for tracking the anticipated required SRC resources needed to support core, communal, SRC activities, and for tracking the pledging of SRC resources into this common pool. The proposal is that the SCC will be chaired by a senior member of the SKAO (most likely the director of operations).

The national representatives of each member state will be responsible for pledges of resources and capabilities to the SKAO as part of the global SRC network. Pledges will be made publicly, as will information on their delivery and the performance of the network as a whole. This model has worked very well for the CERN’s WLCG (The Worldwide LHC Compute Grid), which operates a global collective of processing and data storage over 150 computing centres across more than 40 countries. The WLCG delivers over one million computer cores to physicists and makes use of over an exabyte of storage, e.g., see http://wlcg-cric.cern.ch/core/pledge/list/ so this model is already functioning well at scales similar to those required by the SKA.

Each SRC pledging cycle would occur before the SKA Observatory proposal review process (§6.4.4.4). Anticipated SRC resource requirements will need to draw from results of previous years and look forward to plans regarding KSPs and Observatory upgrades. Once the target for the total pooled SRC resource is agreed upon, individual members would, through appropriate funding agencies, pledge resources through individual SRCs to be made available as part of the SRC network. This collective pool of resources and capability will then be used to support the SKA science programme of KSPs and PI projects.

The reason the definition of a shared pool is so important is that it gives the SKA proposal review process freedom to recommend a science program (allocating telescope and SRC network resources) without the need to attempt to manage national SRC resource allocations. Of course, SKA resources need to be balanced against members’ contribution to the SKA project (in accordance with the access policy, §6.4.1).

Broad agreement between SRC resource needs and SRC resource pledging per nation can (to first order) be ensured if each member’s SRC resource pledge, as a fraction of the total SRC network, aligns with that member’s share of the SKA project. Such a model is anticipated and has the support from the SRCSC.
Any SKA member country could choose to develop SRC resources locally which go beyond the agreed communal pledge amount if they desire. For example, more compute or storage capacity than the amount pledged may be provided only to local/regional users within that SRC’s community.

6.4.5.5.1 Hardware Considerations

A mechanism wherein each SRC puts forward the data storage and processing capability it can offer for SKA-related use over the medium term (e.g., two years) and longer will be needed. These pledges would be fed into the proposal review process to ensure that the overall SRC resource is not overstretched by the projects planned for the coming observing cycles.

A longer-term (greater than 2 years) view of the likely available resources will be used to understand how especially demanding, large-scale, projects (e.g., KSPs with large output data rates) can be planned and supported at SRCs. SRC resource predictions and feedback from the science community will be required to ensure that long term SRC resource planning matches the community needs, and that, conversely, the SKA user community plans experiments that are appropriate within SRC resource and funding caps.

6.4.5.5.2 Software Development Considerations

Each SRC will be different and this heterogeneity must be embraced. However, there will be aspects of user- (and SKAO-) facing software necessary to ensure interoperability between sites. The development work for this software should be centrally managed, enabling much greater efficiencies to be achieved so that each SRC’s software team can benefit from the software developed by other teams. This model of in-kind contributions towards an evolving collective effort has been working very successfully in the SKA’s main software development track during the project’s pre-construction phase – making good use of globally distributed software teams with a broad range of different expertise to contribute to the open-source SKA software codebase\(^\text{15}\). The level of in-kind support will need to be pledged and road mapped in a similar way to the hardware in order to ensure that the work plan is sustainable, but possibly starting much sooner than hardware pledges. There are already active SRC software development projects happening in several locations – coordinating these efforts where appropriate would give better alignment.

6.4.5.5.3 Human Capital Considerations

In addition to hardware and enabling software, SRCs or national SRC offices will need to provide users with access to experts with knowledge of how to use the systems effectively and possibly to give scientific expertise in the interpretation of SKA data products. Such expert staff will need to sit within the SRC organisations, but not necessarily co-located with the SRC infrastructure. Operational support to keep each SRC’s infrastructure running smoothly is essential for the SRC to meet its accreditation requirements, however, the extent of support for more user-facing functions will be determined by each country according to its needs and capacity.

Through the use of a single identity management system across all SRCs, each user will have a single unique ID. The SRC network will be able to monitor the use of its resources by users identified by SKA project ID, member affiliation or any other relevant identified pertinent for accounting purposes. This will enable the SOG and SCC to monitor and check use against agreed limits, compare national fractions with overall pledges and adjust the future roadmap and resource prediction tools as necessary.

6.4.5.6 Governance Considerations

A collaborative partnership between the SKA Observatory and a network of SRCs in the SKA member states is envisaged, providing end-to-end operations under a governance structure illustrated in Figure 19. At meeting BD-34 in September 2020 the SKA Board endorsed this proposed governance model as a starting point for the evolution of a broad and rich set of partnerships between the SKA Observatory and the community to deliver the SKA end-to-end system. At the same meeting, the Board acknowledged the need for the SKA Council to give early attention to issues surrounding national SRC participation.

![Figure 19. SRC network governance, as it relates to the core deliverables of the SKA end-to-end system.](image)

6.4.6 Engineering Operations

Engineering operations comprises those activities necessary for the maintenance of the SKA telescopes and their infrastructure in the host countries. Engineering operations will also be required to support development activities for the SKA telescopes.

The engineering policy will be provided by GHQ and applied by separate engineering groups for each telescope site. These groups will include:

- engineering management to ensure that the engineering policy is applied and coordinated;
- technical staff to carry out normal preventative maintenance;
- engineering and technical staff to carry out specific repairs and modifications;
- systems engineering to manage configuration and performance; and
- software engineers to manage and maintain the software.
6.4.6.1 Availability

The scientific success of the SKA requires that its telescopes be available for science observations for as much of the time as possible within the constraint of available resources. The relevant availability definitions are:

- **Operationally Capable**: An SKA telescope is defined to be operationally capable when it can perform astronomical observations, including signal processing and data reduction, with at least 95% of its collecting area, irrespective of the location of the non-operational receptors.

- **Availability**: The probability that a system is operating to specification at any point in time under stated conditions. It is a measure of how often an item fails (reliability) and how quickly it can be restored to operation (maintainability).

- **Inherent Availability**: The probability that a system is operationally capable at any point in time when used in an *ideal* support environment, i.e., one in which repair commences instantaneously upon failure. It is a measure of how easy it is for an item to be repaired or replaced.

- **Operational Availability**: The probability that a system is operationally capable at any point in time when used in a *realistic* support environment, i.e., one in which repair cannot commence until sometime after the failure has occurred. It is a measure of reliability, maintainability, and the response time of the support system.

- **Science Availability**: The probability that a system is operationally capable at any point in time when used in a realistic support environment including all the factors that can result in the telescope not being available for science. It includes telescope critical failures, replacements (of critical items), software upgrades, maintenance, logistic delays, weather and utility conditions, i.e., power and communications.

The definitions of availability are documented in more detail in [RD8]. The downtime assumptions and estimates at the system critical design review (CDR) are also documented [RD11] and [RD12]. Availability block diagrams, fault tree diagrams, and the single-point failure item list were developed and presented as part of the system CDR documents.

The single-point failures list is used to identify critical items. A minimum inventory level for these items is kept ensuring that a shortfall that may affect the availability of the telescope does not materialise.

Critical services provided by contractors should also be limited as far as possible. Where not possible, these services should be contracted in a way to ensure that operations are not dependent on the performance of external organisations.

Engineering analysis at CDR indicates that the SKA telescopes can offer an inherent availability greater than 95%. From the perspective of observatory operations, however, operational availability is the relevant figure of merit. Both SKA1-LOW and SKA1-MID telescopes have requirements that drive the design to provide an operational availability of 95%.

The system CDR results are described in [RD11] and [RD12] for SKA1-LOW and SKA1-MID, respectively. The following specific conclusions were made regarding the availability requirements during system CDR:

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16 This value is strictly for the purpose of defining availability. It is clearly possible to carry out science observations with less than 95% of the full array.
Inherent Availability
The inherent availability \( (A_i) \) of the SKA1-LOW and SKA1-MID telescopes depends on the design architecture and the MTBF/MTTR estimates. It is estimated that an inherent availability of 99%, is feasible.

Operational Availability
The operational availability \( (A_o) \) of the SKA1-LOW and SKA1-MID telescopes depends on the inherent availability and the level of support and maintenance during operations. Based on the support envisaged, it is estimated that an operational availability between 90 and 95%, is realistic and feasible.

Science Availability
Science availability \( (A_s) \) of the telescopes depends on the operational availability and external downtime contributions including weather, RFI events and utility services. It is estimated that a science availability between 85% and 90%, depending on the external factors, is realistic and feasible.

Achieving this ambitious level of availability requires that:

a) all telescope systems (including both hardware and software) be designed for reliability and maintainability commensurate with this requirement. Allocation of inherent availability to the telescope elements is in [RD8];

b) the support system be designed to provide a response time commensurate with this requirement. The support concept is described in [RD9]; and

c) the availability and maintenance strategy should continually be evaluated and improved where possible.

In addition, the scale of the SKA demands an industrial level of logistics engineering – the integrated logistics support plan is at [RD10].

The definitions and requirements given above are based on probability and are appropriate for engineering design purposes. In practice, however, the actual availability will be monitored post-facto. The requirement in this case shall be interpreted to refer to the average operational availability achieved over any significant length of time, e.g., the observing cycle or a calendar year.

The availability definition given above is intended to be generally applicable. The SKA design, however, is extremely flexible and allows for multiple configurations. The availability definition must therefore be tailored for application in some specific situations.

6.4.6.2 Technical operations
Technical operations at the telescope sites are envisaged to take place in a similar way at the SKA1-LOW and SKA1-MID sites. The following activities are considered within the scope of technical operations.

System engineering and performance analysis
Each subsystem of the SKA provides real-time metrology that monitors the performance and status of its LRU components during operations. This monitoring generates diagnostics to track the performance of the global system.

Troubleshooting and corrective maintenance
Despite the efforts to provide a fully functioning and reliable system, we should anticipate the continuous need for intervention, particularly during the first years of operation. Trained and experienced engineers
will keep the telescopes, arrays, and instruments functional. It is necessary that an understanding of root causes of failures is established. This will require the presence of highly skilled mechanical, electronic, and software engineers with a deep know-how and understanding of the systems.

Instrument/software handling

New SKA instrumentation, equipment, and software will be assembled, integrated, and verified before shipment to the site according to their respective statement of works. The process of preparation on site will be organised in the following steps:

- re-integration (in case it cannot be shipped fully assembled) and (re-)testing at the EOC;
- integration on-site or, for SKA1-MID, on the dishes;
- on-site commissioning; and
- acceptance (see §6.4.9.3).

Handling and transportation from the integration facility to its installed location shall occur with the minimum number of lifting processes (if appropriate). This is to limit one of the highest risks of such an operation. The hand over process, as well as acceptance by the Telescope Director, will follow a defined procedure.

Any assembly will be carried out in the EOC (or by the OEM in their integration facility) to reduce the time necessary at the telescope sites, thus limiting interference with routine telescope operations, as well as minimising RFI.

Once an instrument or component has been accepted by the Observatory it shall be under strict configuration control (to include hardware, software, documentation, manuals, drawings, etc.). The engineering operations teams will be responsible for its performance, maintenance, and configuration control.

Instrument support

There will be the continuous need of specialised crews of technicians and engineers to maintain SKA telescopes and their instrumentation. They will also support the installation of new instruments and equipment and work together with instrument scientists to debug problems arising.

6.4.6.3 Maintenance Strategy

A major challenge for any observatory is to achieve the optimal balance between science operations and engineering operations. This tension arises because maintenance activities will, in general, compromise availability and therefore scientific productivity, in the short term. Maintenance is nevertheless essential, not only to repair faults so that science observations can proceed but also to ensure the long-term health of the telescope facilities. The SKA poses unique challenges in this respect due to its unprecedented scale. Obtaining the appropriate balance will be an evolutionary process.

Availability of the SKA telescopes will be enabled by design reliability and maintainability characteristics and a structured programme of preventive and corrective maintenance. Telescope maintenance will use engineering subarrays. In order to comply with the operational availability
requirements, science will generally proceed on one or more science subarrays in parallel with maintenance. The maintenance plan will describe both preventive maintenance and corrective maintenance, varying from system to system, depending on the known failure modes. The strategy is informed by a standard failure modes, effects, and criticality analysis (FMECA) of each telescope system.

Statistical data analysis will be used to determine and predict the reliability of the equipment. Precursor failure data analysis will be used instead of traditional Mil-Handbook prediction methods.

Dish and station failures will not have a significant impact on the telescope’s availability, and services will be performed during operation. A dish/station that has degraded below the acceptable level will be assigned to an engineering array for repairs. Inspection and services will be performed on a fixed time interval per dish. A 12 monthly maintenance window will be applicable to the MID dish. It is envisaged that each LOW station in the core and RPF, and their associated stations, will be visited on a 15 to 18-week cycle. Maintenance personnel will replace defective antennas and LNAs, maintain RPFs, as well as inspect the vegetation on the station’s foundations.

Condition-based maintenance, and where applicable a run-to-failure philosophy, will be used to ensure minimum downtime and RF interference. Condition-based maintenance is a means of preventive maintenance and refers to scheduling maintenance inspections, servicing, and parts replacement according to the measured/inspected condition of equipment. Condition-based maintenance will be considered for telescope items for which detection of degradation (e.g., increased vibration, contamination of lubricants, etc.) is feasible and for which failure can be prevented by maintenance. Results of inspections, measurements, and monitoring will be interpreted to schedule servicing and parts replacement tasks in accordance with the telescope condition-based maintenance instructions.

Maintenance activities during operation will have an impact on the RFI footprint. It is envisaged that this interference will occur daily during business hours. This interference will be in the form of vehicle movement, cherry pickers, dish repair, and on-site testing activities. Maintenance activities will be conducted in such a way as to minimise the interference and scheduled to minimise the impact on science operations. The impact of RFI during maintenance activities is included in the science availability estimations. It is further estimated that external RFI events will be minimal.

Repair work in the field will be minimised. Maintenance of stations and dishes will be carried out at various locations in the array to minimise the impact on the telescope’s science programme. All on-site telescope systems are designed to make maximal use of Line replaceable units (LRUs). The normal response, in the event of a fault, will be to replace the faulty unit with a working spare and to send the faulty unit for repair or replacement off-site. An inventory of working spares must therefore be maintained.

Work orders will be created for all repair and scheduled maintenance activities, including statutory and safety management activities. These work orders will be allocated to maintenance personnel. The maintenance management software (§6.4.6.11) will track resource usage, to ensure that adequate levels of support resources, personnel, and spares are available. It will also assist to ensure that the observatory does not experience downtime from failures or unnecessary expenditure on inefficient maintenance procedures. All software versions will be identified and reported against the maintenance structure.

In order to minimise the number of staff needed at each telescope site, and to run operations and maintenance efficiently, a remote diagnostic capability is essential (§6.4.6.5). Each subsystem of the
SKA provides real-time metrology that monitors performance and status during operations. The subsystem monitoring forms an integral part of operations and, in this way, every observation is also an engineering test of the system. Apart from the subsystem level monitoring, daily logging activities generate useful diagnostics for the performance of the global system. Monitoring of the overall metrics from the telescope forms a key task of the operations team.

Given the scale of the SKA telescopes, in terms of both size and geographical distribution, it is not envisaged that the entire array will be taken down for maintenance; rather, maintenance work on the front-end systems will, in general, take place whilst observations are in progress. Individual stations or dishes, for example, will be removed from service as required and assigned to an engineering subarray (§6.4.4.7) for work to be carried out. It will be the responsibility of the Telescope Operator to manage the switching of individual components in and out of service. Single-point failures and software updates, however, may require taking an entire telescope out of service for a period.

Software updates shall occur with little to no downtime. Downtime for updating software and/or preventive re-initialisation shall comply with the operational availability requirement.

Given the scale of the two SKA telescopes and the level of redundancy, it is not anticipated that there will be designated maintenance windows during the week when each telescope will not be available for science.

The approaches to RFI management, safety management, and security management will be structured to allow sufficient access for maintaining the SKA telescopes' operational availability.

Repair activities by the OEM and service level agreements (SLAs) will be managed by operations personnel. Any regular work orders/job cards will automatically be provided and sent to the OEM or service provider to notify them of the work requirements.

6.4.6.4 Failure Data Analysis

An aperture array telescope is inherently robust, and many failure modes are not critical. The size of the array and the distributed processing are responsible for a large number of redundancies. During the design phase of the SKA, an inherent availability target of 99% was assigned to most sub-elements and compliance was demonstrated during the various sub-element CDRs. By evaluating precursor data and ensuring that the correct spare parts are stocked, a telescope operational availability of between 90 and 95% was found to be feasible.

The mean time between failure (MTBF) and the mean time to recover (MTTR) are general statistics for reliability and maintenance. However, these parameters do not contain all the necessary information and in most cases are inaccurate. A database has been developed with the current estimates and provides a basis for further analysis. Better estimates are being developed and will continue to mature as more information becomes available.

At the time of writing, the MeerKAT telescope has been in operation for two years. The faults and repair data of the telescope was evaluated, and many maintenance tasks for inspection were found in the current maintenance plan and data. Many early construction repair tasks were also performed, as might be expected for a new system. There are currently 3 teams of 4-5 people who mainly do services and repairs on 64 MeerKAT dishes once a week. The MeerKAT receivers are currently being maintained with an effective conditioning monitoring program. A mid-range condition monitoring program will be developed of a similar nature, based on lessons learned from the MeerKAT approach.
Except for servo problems, and if all infant mortality failures\textsuperscript{17} are filtered out, the MeerKAT system seems to be reliable. The calculated availability percentages are also much the same as expected for SKA1-MID Dishes. The simulation model (see §6.4.6.7) was adapted with data and concepts learned during this analysis of failures. Equivalent data for low-frequency arrays is much more limited but is actively being sought from contacts at MWA and LOFAR\textsuperscript{18}.

6.4.6.5 Failure Detection and Identification and Remote Diagnostics

An objective for the SKA telescope design is to enable prompt restoration after a component failure. Identifying the failed replaceable unit is critical to minimising telescope downtime. A telescope health monitoring diagnostic system will be implemented and will enable:

- confirmation of telescope health for context of use;
- detection of failures;
- identification of operating fault cause to the level required for repair;
- identification of fault cause to the level required for repair of LRUs in off-site facilities;
- verification of repairs, prior to returning to service;
- control of health test/diagnosis risk to personnel, the telescope or environment;
- confirmation of health monitoring functionality, as a basis for confidence in the reported health status; and
- cost-effective telescope operation and support.

Diagnostic monitoring will be automated to enable short response times. The Telescope Manager will provide the Operator with online telescope status information to identify failures. This will be in the form of alarms and monitored sensor data aggregated from local monitoring & controls (LMCs). The fault detection and diagnostic performance will enable compliance with the operational availability downtime requirement. In the event of a failure, the objective is for the diagnostic system to automatically identify the fault to the level of the LRU requiring repair.

Telescope health monitoring will provide remote access diagnostic capabilities. Engineering operations personnel will have access to remote diagnosis features so that maintenance and repair activities can be planned and carried out efficiently. The Telescope Operator and engineering staff will regularly monitor the system’s health indicators, logs, and condition, with the ability for remote interrogation of sensor values as required. Once resources are placed in an engineering subarray, control of those resources may be ceded to local control by the Operator to allow maintenance staff to carry out testing, maintenance, or corrective procedures.

Testability requirements analysis will identify and prioritise failure modes to be detected and identified. Telescope health test performance requirements will be developed at the system and equipment level and will be traceable to design failure modes, effects, and criticality analysis (FMECA). Telescope health test approaches will allow a margin for adjustment consistent with the failure characteristics of the telescopes. The SKA operational testability standard (to be written) will describe the health test performance requirements and constraints.

Telescope condition and failure behaviour will be tracked to ensure alignment between the telescope monitoring performance and the telescope operational behaviour. Monitoring will be aligned mainly

\textsuperscript{17} Failures that occur prematurely. Such failures can occur due to inadequate designs, inferior materials, poor workmanship, improper installation, or other quality problems in work that was done prior to an asset entering service.

\textsuperscript{18} This work will continue to evolve and improve as more data becomes available, especially from the aperture array verification systems (AAVS1 and AAVS2) for SKA1-LOW.
by way of configuring logging, status processing, and aggregation in the LMCs and Telescope Manager (TM). This will be an ongoing process through construction and into telescope operations.

The SKA failure recording analysis and corrective action system (FRACAS)\(^\text{19}\) will be operational from the start of construction to capture failure data and assess diagnostic performance. The engineering management system (EMS) interfaces with TM for equipment maintenance-related operating parameter and status information (see §6.4.6.11). Telescope FMECA data will be continuously updated in the EMS, as references for fault-finding, status aggregation, and condition-based maintenance.

The telescope FMECA and health test configuration data will form part of the testability baseline deliverable for the operational baseline. Testability baselines shall be maintained during the life cycle to enable effective ongoing operation and engineering support.

6.4.6.6 Personnel and Training

The SKA telescopes will be managed, operated and supported by personnel with suitable qualifications and experience. SKA personnel profiles and training requirements will take account of statutory certification requirements applicable to the telescope operating and maintenance roles.

The maintenance teams will be composed of technical persons that are skilled and qualified with appropriate technical training. They will be responsible for corrective and preventive maintenance and also involved during operations to regularly monitor the system health indicators and logs. When authorised by the Telescope Operator, the maintenance team will be able to take manual control of resources for the purposes of testing.

A guiding principle has been to design the system to minimise the number of operational staff required on the telescope sites to maintain them. This strategy is analysed as part of the logistic support analysis (see §6.4.6.7) to ensure that only small teams will be required on the sites.

Personnel will be equipped with skills to competently perform SKA operating and maintenance task requirements. Trade-qualified maintenance personnel will receive SKA subject training to be competent for SKA maintenance tasks. Training shall include site policies and practices relevant to the scope of work, including training of industry support personnel accessing the site.

Training capabilities for the SKA will be formalised as an ongoing capability for the Observatory to maintain aptitudes and attitudes required. Personnel trained and suitably experienced during construction and commissioning will play a key role in ongoing training delivery. Training packs and instructional capabilities will be qualified as part of establishing the SKA operational baseline.

6.4.6.7 Maintenance Management and Implementation

A simulation model for SKA engineering operations has been developed based on data in the support database. The model simulates 10 years of operation and uses mean time between failures (MTBF) and mean time to repair (MTTR) values that were supplied by design consortia for their element CDRs during the pre-construction phase of the SKA project. The model recognises the single-point failures with each element and their sub-systems. The simulation was used to validate the SKA support concept [RD9] and the strategy and implementation of the maintenance plan for each of the SKA telescopes.

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\(^{19}\) FRACAS is a capability of the SKAO engineering management system (EMS).
As with any model, there are a number of assumption and caveats. The principal assumptions are:

- a working day is 8-hours, spanning 0800-1600;
- a 5-day working week is Monday to Friday;
- a total of 220 workdays are available per year\textsuperscript{20}, to account for annual leave, holidays, and other absences; and
- travel times to and from the site are assumed and accounted for, including the time to travel to and along the spiral arms.

Furthermore, the model assumes that effective support procedures will be developed, implemented, and managed. It also assumes that the correct parts are purchased, staff are trained with the necessary skills, and the maintenance philosophy is optimised.

It should be noted that there is no accommodation for “disaster scenarios”, e.g., an extended period when the telescope site is not reachable by staff as a result of a severe storm. The model will therefore tend to overestimate the telescope availability. Scenario planning for such events will be carried out periodically by the operations teams across the Observatory, with a view to improving operational procedures when such events occur, and a register to track their risks and mitigations will be maintained.

### 6.4.6.7.1 Definitions: Preventative and Corrective Maintenance

The following definitions apply where it comes to the maintenance of the telescope resources.

| Preventative/Scheduled Maintenance | Maintenance that requires the resource or component/element (e.g., antenna, station, RPF, maser) to be unavailable for observing. Maintenance can be scheduled during science observing on the rest of the telescope, helping to maintain the availability of the telescope. |
| Corrective Maintenance | The resource is not available for science observations due to critical system failures and repairs. Depending on the nature and criticality of the element, the telescope may not be available for observing. |

### 6.4.6.7.2 Working Patterns

Given the different geographical locations of the two SKA telescopes, the working patterns for the two will differ. This is mostly driven by the fact that the location of the EOC for SKA1-LOW is in Geraldton, some 350 km from the site at the Murchison Radio-astronomy Observatory (MRO), while the EOC for SKA1-MID is in Klerefontein, a comparatively closer 70 km from the site and close to the town of Carnarvon. We anticipate that most of the technical staff, whether working on the site or at the EOC, will reside in Geraldton (for SKA1-LOW) or Carnarvon (for SKA1-MID).

For SKA1-LOW, we anticipate replicating the existing working pattern of CSIRO staff operating the MRO and the ASKAP telescope. SKA engineering operations staff will fly into the MRO on Monday morning from Geraldton, stay at the Boolardy Accommodation Facility during the week before flying back to Geraldton on Friday afternoon. Driving to and from the site for transporting larger and heavier equipment, for instance, is possible but takes considerably longer. It is anticipated that a 15-18-week maintenance cycle will be employed wherein each of the 36 remote processing facilities (RPFs), including the 6 stations attached to each RPF, will be visited for preventative maintenance work. Similar work in the core and central processing facility (CPF) will be continuous during this period.

\textsuperscript{20} These values are adopted based on the experience of both CSIRO and SARAO.
Table 26: Examples of preventative maintenance work.

<table>
<thead>
<tr>
<th>Task</th>
<th>Telescope</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPF and core maintenance cycle</td>
<td>SKA1-LOW</td>
<td>Regular inspect and clean service following a regular preventative maintenance cycle.</td>
</tr>
<tr>
<td>Dish maintenance</td>
<td>SKA1-MID</td>
<td>Regular inspect and clean service following a regular preventative maintenance cycle.</td>
</tr>
<tr>
<td>Power and electrical inspection and maintenance</td>
<td>BOTH</td>
<td>Power cable inspections, transformer services, breaker tests, UPS batteries, diesel generator and DRUPS service and test, load tests, gridline tests and maintenance, PV plant maintenance and cleaning.</td>
</tr>
<tr>
<td>HVAC</td>
<td>BOTH</td>
<td>Monthly HVAC inspection and cleaning.</td>
</tr>
<tr>
<td>UTC calibration</td>
<td>BOTH</td>
<td>Annual calibration tests.</td>
</tr>
</tbody>
</table>

Table 26 gives some high-level examples of preventative maintenance work that will be carried out for the SKA1-LOW and SKA1-MID telescopes. By estimating the time for these and other maintenance or repair tasks, it is possible to model the size of the workforce required to support the operations of the SKA telescopes and keep the telescopes within the 95% availability requirement.

The model also takes into account the travel time required to undertake a particular task. For the different roles that have been identified to support the operations and maintenance of each SKA telescope (see Table 27 and Table 29 below), the travel time makes up a significant fraction of the available work time given the size of each array and the distributed nature of the operational model (e.g., the distance between the EOC and the site, and between the core and the spiral arms).

6.4.6.8 Maintenance Roles and Staffing – SKA1-LOW

A total of 15 separate roles have been identified for the support of operations and maintenance of the SKA1-LOW telescope (not including the management roles). Of these, 12 are technical roles. Role descriptions and staffing numbers are provided in Table 27 and work patterns are illustrated in Figure 20. At any one time, most of the staff are located at the EOC, minimising the number of staff at the telescope site and their RFI impact. Each week, starting on a Monday, a team of approximately 8-15 people will fly into the site to begin working on the scheduled maintenance and critical repairs for that week, residing at the Boolardy Accommodation Facility until their return to Geraldton on Friday afternoon. Of course, this number will vary depending on the nature and volume of work required at any point in time.

Work will be distributed between the core and the spiral arms. For the most part, the work will be based on an ‘inspect and replace’ basis, so that if anything cannot be quickly and easily fixed in situ, it is replaced with an LRU (or removed from service until it can be) and the faulty component returned to EOC for further fault diagnosis and repair. Prior identification of faulty components/LRUs is necessary so that the maintenance team can take the appropriate spare with them. The fault logging and EMS system will be able to provide this information.

The support model for the maintenance of the telescope is such that each of the 36 RPFs is visited over a 15-18-week cycle so that, on average, each RPF is visited and inspected approximately 3 times
per year. Meanwhile, work in the core is performed on a station-to-station basis and is a continuous, on-going process.

The maintenance teams scheduled to fly-in and fly-out of the telescope site will have to be carefully managed, along with the work scheduled to be undertaken. This work needs to be selected and matched to the skills of the technical and engineering staff available and as described in Table 27 (see also Figure 21). The “multi-skiiling” and cross-training of technical staff will be important to ensure this model is effective.

![Diagram of maintenance teams and work schedule]

Figure 20. Framework model of the working pattern for engineering operations and maintenance of the SKA1-LOW telescope. Staff roles undertaking work at the telescope site (blue) and the EOC in Geraldton (red) are shown. The maintenance teams working on-site are selected from the individual teams. Role descriptions, and the number of staff in each role, are given in Table 27. Roles R8, R9, and R11 are non-technical roles and not shown here.

Emergency/out-of-hours work (i.e., late evenings and weekends) may be required on occasion for problems that cannot be dealt with remotely by the Telescope Operator. During the week, late-night emergencies may be dealt with by SKA staff resident at the Boolardy Accommodation Facility (with possible knock-on effects on their work schedule the next day due to lost sleep). Given the distance of the EOC/Geraldton from the site, weekend emergencies will be more challenging to accommodate. A rota of staff can be available on-call to go to the site to fix critical problems that arise at these times, but they will have to be the kind of problems that present a safety risk to personnel or the telescope if not dealt with relatively quickly. In some cases, it may be that if the problem persists but does not pose a safety risk, science time may be lost.
Table 27: Role descriptions for maintenance of SKA1-LOW, including the number of staff in each role. Engineering level staff are identified by the asterisk.

<table>
<thead>
<tr>
<th>Role</th>
<th>Function</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance Teams</td>
<td>RPF Preventative and Corrective Maintenance</td>
<td>Inspect/clean/repair and replacement of station components. Replace LRUs, power, cooling, cabling, stations, networks, boards, cooling, antenna pyramid, antenna, modules, cabling, general maintenance.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Antenna Core Preventative and Corrective Maintenance</td>
<td>Replace LRUs, network components, boards, power supplies, cooling, masers, cabling, general maintenance.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CPF Preventative and Corrective Maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>SKA-LOW Station Engineer</td>
<td>TPM and MCCS units, servers, Rack cooling components, Muxponders.</td>
<td>1*</td>
</tr>
<tr>
<td>R2</td>
<td>Electrical</td>
<td>Electrical repairs and inspections.</td>
<td>3 + 1*</td>
</tr>
<tr>
<td>R3</td>
<td>HVAC</td>
<td>HVAC repairs and inspections.</td>
<td>2</td>
</tr>
<tr>
<td>R4</td>
<td>SAT</td>
<td>Signal and Timing LRUs.</td>
<td>1*</td>
</tr>
<tr>
<td>R5</td>
<td>Networks</td>
<td>Network switches, switches, cable repair network manager (NMGR), network set up and monitoring.</td>
<td>1*</td>
</tr>
<tr>
<td>R6</td>
<td>RFI</td>
<td>Testing for RFI compliance of incoming or repaired items. RFI test and monitoring campaigns on site.</td>
<td>4 + 1*</td>
</tr>
<tr>
<td>R7</td>
<td>Acceptance and Compliance</td>
<td>Acceptance testing of new and repaired equipment.</td>
<td>2</td>
</tr>
<tr>
<td>R8</td>
<td>Purchasing</td>
<td>Purchasing spare parts and consumables.</td>
<td>2</td>
</tr>
<tr>
<td>R9</td>
<td>Contract Management</td>
<td>Management of SLAs and external contracts.</td>
<td>1</td>
</tr>
<tr>
<td>R10</td>
<td>Inventory and Logistics</td>
<td>Inventory and stores management.</td>
<td>2</td>
</tr>
<tr>
<td>R11</td>
<td>Admin and Office Support</td>
<td>Administration support for the management team and EOC staff, including HR.</td>
<td>2</td>
</tr>
<tr>
<td>R12</td>
<td>IT and Networks Support</td>
<td>IT support services for EOC and CPF.</td>
<td>4</td>
</tr>
<tr>
<td>R13</td>
<td>HSE Officer</td>
<td>Monitoring HSE on-site and at EOC.</td>
<td>1</td>
</tr>
<tr>
<td>R14</td>
<td>Coordinator/Planner</td>
<td>Logistics planning for personnel on-site.</td>
<td>2</td>
</tr>
<tr>
<td>R15</td>
<td>SKA-LOW Telescope Maintenance Technicians</td>
<td>Maintenance of antenna stations and RPFs.</td>
<td>20</td>
</tr>
<tr>
<td>R16</td>
<td>Communications and Outreach</td>
<td>Local communications and outreach activities.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>FPGA Engineers</td>
<td>Firmware programming of FPGAs for PSS and PST.</td>
<td>2</td>
</tr>
</tbody>
</table>

TOTAL: 53

In addition to the site maintenance teams, other roles support the engineering operations and maintenance of the SKA1-LOW telescope. These are identified in Table 27. These positions are either technicians, engineers (identified by the asterisk), or serve as part of the administration support team.
Senior management positions are also required in order to manage the site and EOC as well as to direct the work. The role descriptions for these are given in Table 28, with an assumed group and management structure shown in Figure 21. All except MR4 need to be engineers. The SKA-LOW Head of Engineering Operations will report to the SKA-LOW deputy Telescope Director. The HSE Manager will report directly to the SKA-LOW Telescope Director. The FPGA Engineers do not have an explicit role identification as they will be located at the SOC rather than the EOC. However, as part of the engineering operations group, their role description is provided here for completeness.

Table 28: Role descriptions for management roles for SKA1-LOW telescope operations and maintenance.

<table>
<thead>
<tr>
<th>Role</th>
<th>Function</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR1</td>
<td>SKA-LOW Head of Engineering Operations</td>
<td>Management of site, facilities and engineering personnel on telescope site and at the EOC. Reports to the Deputy Telescope Director.</td>
<td>1</td>
</tr>
<tr>
<td>MR2</td>
<td>Stores Manager</td>
<td>Asset management and inventory. Planning of work carried out in EOC for quality assurance, acceptance and compliance of equipment for the site.</td>
<td>1</td>
</tr>
<tr>
<td>MR3</td>
<td>Telescope Engineering Manager</td>
<td>Management and planning of maintenance work on-site and at EOC, quality assurance, responding to and managing related faults.</td>
<td>1</td>
</tr>
<tr>
<td>MR4</td>
<td>Financial and Administration Manager</td>
<td>Management of budgets and administration for the EOC.</td>
<td>1</td>
</tr>
<tr>
<td>MR5</td>
<td>HSE Manager</td>
<td>Ensure that all HSE standards are met and followed. Training. Reports directly to the Telescope Director.</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>5</strong></td>
</tr>
</tbody>
</table>

Altogether, in order to maintain and run the engineering operations and maintenance of the SKA1-LOW telescope, a total staff of 58 is required. All will be based at the EOC and will only travel to the site as and when required or scheduled.
6.4.6.8.1 SKA1-LOW Station Availability

The result of the 10-year simulation is an indication of the probability of how many stations are available for science, and how many are unavailable and assigned to an engineering subarray for maintenance (whether preventative or corrective). Figure 22 shows the resulting probability density function from the SKA1-LOW model, for the staffing numbers in Table 27. The chart shows the probability that, at any given time, a given number of stations will not be available for science operations. The model predicts that, at any given time, there is a 95% probability that 99% of the stations will be available.

It is not just the number of unavailable stations that is important but also the location of those stations in the array and how the science might thus be impacted. For instance, an unavailable station located in the core will have a lower negative impact on the science than if that station were located along a spiral arm. As such, in planning maintenance, priority will be given to those stations located along the spiral arms in order to bring them back into operation as soon as possible.
Figure 22. Probability (left axis, red shading) that a number of stations (x-axis) in the SKA1-LOW telescope are unavailable for science operations, on average, at any given time. The cumulative probability (right axis, blue curve) is also shown. If the array is regularly maintained (and ignoring external influences such as weather and power outages) there is a 95% probability that, at any given time, up to 99% of the stations will be available.

Note that this is a steady-state model and gives an indication of the availability that results from the staffing levels assumed (predicated by the assumptions detailed in §6.4.6.7). Adjusting the working pattern or the staffing levels will change the availability results in Figure 22. If for any reason a backlog builds and an increasing number of stations become unavailable, then it will not be possible to reduce the backlog with the same maintenance team – they can only work on a set number of RPFs and stations per week. At such times, or when the backlog grows beyond a certain trigger point (e.g., approaching the 95% availability metric), more staff will be mobilised from the existing workforce (i.e., from the other technical roles described in Table 27, or from elsewhere in the Observatory) to repair and deliver stations back into service.

6.4.6.9 Maintenance Roles and Staffing – SKA1-MID

A total of 17 separate roles have been identified for the support of operations and maintenance of the SKA1-MID telescope (not including management roles). Of these, 14 are technical roles. Role descriptions and staffing numbers are provided in Table 29 and work patterns are illustrated in Figure 23.

At any one time, most of the staff will be at the EOC, minimising the number of staff at the telescope site and their RFI impact. Each day, a team of approximately 8-15 people will drive to the telescope site from the EOC at Klerefontein to begin working on scheduled maintenance and critical repairs. Of course, this number will vary depending on the nature and volume of work required at any point in time. Work will be distributed between the core and the spiral arms. For the most part, the work will be based on an “inspect and replace” basis, so that if anything cannot be simply fixed in situ, it is replaced with an LRU (or removed from service until which time it can be) and the faulty component returned to EOC for further fault diagnosis and repair. Prior identification of faulty components/LRUs is necessary so that the appropriate spare can travel with the maintenance team. The fault logging and EMS system will provide this information.
Maintenance teams working on-site undertake preventative and corrective maintenance of dishes in the core and along the spiral arms. The support model is built so that each dish is visited at least once every 12 months. There may be the occasional need for larger teams of technical and engineering staff to travel to site to work on specific problems on specific components/elements within the dishes or the CPF. Generally, there will be a sizable team based at the EOC working on other duties (such as testing or repairing faulty equipment).

Figure 23. The framework model of the working pattern for engineering operations and maintenance at the SKA1-MID telescope. Staff roles undertaking work at the telescope site (blue) and the EOC in Klerefontein (red) are shown, with the different roles needed to support the maintenance activities indicated. Role descriptions and the number of staff in each role are given in Table 29. Roles R10, R11, and R13 are non-technical roles and not shown here.

Emergency/out-of-hours work (i.e., late evenings and weekends) may be required on occasion. A rota of staff will be available on-call to go to the site to fix critical problems that arise during these periods and which cannot be dealt with remotely by the Telescope Operator. The kind of problems envisaged are those that may present a safety risk to the telescope or personnel if not dealt with relatively quickly, or that are adversely impacting the science programme.

In addition to the site maintenance teams, other roles support the engineering operations and maintenance of the SKA1-MID telescope. These are identified in Table 29, describing either technicians, engineers (identified by the asterisk), or as part of the administration support team. Senior management positions are given in Table 30. The assumed management structure is shown in Figure 24. All except MR4 need to be engineers. The SKA1-MID Head of Engineering Operations will report to the SKA-MID Deputy Telescope Director. The HSE Manager will report directly to the SKA-MID Telescope Director. The FPGA Engineers do not have an explicit role identification as they will be located at the SOC rather than the EOC. However, as part of the engineering operations group, their role description is provided here for completeness.
Table 29: Role descriptions for maintenance and support of SKA1-MID, including number of staff in each role.

<table>
<thead>
<tr>
<th>Role</th>
<th>Function</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maintenance Teams</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spiral Arm Preventative and Corrective Maintenance</td>
<td>Inspect/clean/repair and replacement of dish components. Replace LRUs, power, cooling, cabling, networks, boards, cooling, cryogenics, modules, cabling, general maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core Preventative and Corrective Maintenance</td>
<td>Replace LRUs, network components, boards, power supplies, cooling, masers, cabling, general maintenance.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPF Preventative and Corrective Maintenance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R1 Mechanical</td>
<td>Mechanical engineering for dishes, drives, and motors.</td>
<td>1*</td>
<td></td>
</tr>
<tr>
<td>R2 Electrical</td>
<td>Electrical repairs and inspections.</td>
<td>2 + 1*</td>
<td></td>
</tr>
<tr>
<td>R3 HVAC</td>
<td>HVAC repairs and inspections.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>R4 SAT</td>
<td>Signal and timing LRUs.</td>
<td>1*</td>
<td></td>
</tr>
<tr>
<td>R5 Networks</td>
<td>Network switches, switches, cable repair network manager (NMGR), network set up and monitoring.</td>
<td>1*</td>
<td></td>
</tr>
<tr>
<td>R6 RFI</td>
<td>Testing for RFI compliance of incoming or repaired items. RFI test and monitoring campaigns on-site.</td>
<td>2 + 1*</td>
<td></td>
</tr>
<tr>
<td>R7 Cryogenics</td>
<td>Repair and testing of cryogenic cooling equipment, including helium systems.</td>
<td>4 + 1*</td>
<td></td>
</tr>
<tr>
<td>R8 Acceptance and Compliance</td>
<td>Acceptance testing of new and repaired equipment.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>R9 Receivers</td>
<td>Repair, maintenance and functional testing of receiver equipment.</td>
<td>3 + 1*</td>
<td></td>
</tr>
<tr>
<td>R10 Purchasing</td>
<td>Purchasing spare parts and consumables.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>R11 Contract Management</td>
<td>Management of SLAs and external contracts.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>R12 Inventory and Logistics</td>
<td>Inventory and stores management.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>R13 Admin Support</td>
<td>Administration support for the management team and EOC staff, including HR.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>R14 IT and Networks</td>
<td>IT support for EOC and CPF.</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>R15 HSE Officer</td>
<td>Monitoring HSE on-site and at EOC.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>R16 Coordinator/Planner</td>
<td>Logistics planning for personnel on-site.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>R17 SKA-Mid Telescope Maintenance Technician</td>
<td>Maintenance of dishes.</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>R18 Communications and Outreach</td>
<td>Local communications and outreach activities.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>FPGA Engineers</td>
<td>Firmware programming of FPGAs for PSS and PST.</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td>63</td>
</tr>
</tbody>
</table>
Table 30: Role descriptions for management roles for SKA1-MID telescope operations and maintenance.

<table>
<thead>
<tr>
<th>Role</th>
<th>Function</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR1</td>
<td>SKA-MID Head of Engineering Operations</td>
<td>Management of site, facilities, and engineering personnel on-site and at the EOC. Reports to the Deputy Telescope Director.</td>
<td>1</td>
</tr>
<tr>
<td>MR2</td>
<td>Stores Manager</td>
<td>Asset management and inventory. Planning of work carried out in EOC for quality assurance, acceptance, and compliance of equipment for the site.</td>
<td>1</td>
</tr>
<tr>
<td>MR3</td>
<td>Telescope Engineering Manager</td>
<td>Management and planning of maintenance work on-site and at EOC, quality assurance, responding to and managing faults.</td>
<td>1</td>
</tr>
<tr>
<td>MR4</td>
<td>Financial and Administration Manager</td>
<td>Management of budgets and administration of the EOC.</td>
<td>1</td>
</tr>
<tr>
<td>MR5</td>
<td>HSE Manager</td>
<td>Ensure that all HSE standards are met and followed. Training. Reports to the Telescope Director.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>5</strong></td>
</tr>
</tbody>
</table>

Altogether, in order to maintain and run the engineering operations and maintenance of the SKA1-MID telescope, a total staff of 68 is required. All will be based at the EOC and will only travel to the site as and when required or scheduled.
Figure 24. The management structure for running the operations and maintenance of the SKA1-MID telescope from the EOC in Klerefontein. The Telescope Director and Deputy Telescope Director will normally be located at the SOC in Cape Town.

6.4.6.9.1 SKA1-MID Dish Availability

The result of the 10-year simulation is an indication of the probability of how many dishes are available for science, and how many are unavailable and assigned to an engineering subarray for maintenance (whether preventative or corrective). Figure 25 shows the resulting probability density function from the SKA1-MID model, for the staffing numbers in Table 29. The chart shows the probability that, at any given time, a given number of dishes will not be available for science operations. Similar to that described for SKA-LOW (§6.4.6.8.1), there is a 96% probability that at least 95% of the dishes will be available.

Similar to SKA1-LOW, the location of the unavailable dishes is important to consider as this may impact the science programme. Priority will be given to those dishes located along the spiral arms in order to bring them back into operation as soon as possible.

Note that this is a steady-state model giving a good indication of the staffing levels required (predicated by the assumptions detailed in §6.4.6.7). Adjusting the working pattern or the staffing levels will change the availability curve in Figure 25. If for any reason a backlog builds and an increasing number of dishes become unavailable, then it will not be possible to reduce the backlog with the same maintenance team – they can only work on a set number of dishes per week. At such times, or when the backlog grows beyond a certain trigger point (e.g., approaching the 95% availability metric), then more staff will be mobilised from the existing workforce (i.e., from the other technical roles described in Table 29 or elsewhere within the Observatory) to repair and deliver dishes back into service.
Figure 25. Probability (left axis, red shading) that a number of dishes (x-axis) in the SKA1-MID telescope (of both MeerKAT and SKA1 dishes) are unavailable for science operations, on average, at any given time. The cumulative probability (right axis, blue curve) is also shown. If the array is regularly maintained (and ignoring external influences such as weather and power outages) there is a 96% probability that at least 95% of the dishes will be available.

6.4.6.10 Maintenance Contracting, Warranty, and Service Level Agreements (SLAs)

All items delivered to the SKA Observatory shall be supported by a supplier warranty. Warranty conditions shall be agreed, accounting for storage at SKA facilities, handling, application and support context, and environment. Parties contracted to the SKAO for installing supplied items shall take on the warranty obligations of the original supplier. The Head of Engineering ODperations for each telescope is responsible for managing warranty claims, supported by staff within the relevant group.

Warranty agreements shall clearly define the obligations, constraints, and any associated non-warranty cost implications for problem investigation, item removal, storage, packaging, insurance, transportation, importation, repair, re-installation, and verification. Items delivered to SKAO shall be managed for compliance to warranty conditions for notification, item preparation, preservation, packaging, handling, storage, transportation, storage, installation, maintenance, and use. Each telescope element/component will have operational maintenance plans that will identify items under warranty and provide a reference for maintainers to the warranty schedules, conditions, and compliance process.

In general, the SKAO will establish support capabilities addressing requirements feasible and economical to sustain in-house. The balance of the Observatory support requirements will be outsourced. Special investment in internal capabilities will be considered where reliance on external supply is not feasible/dependable. This may be combined with strategic agreements for sustaining key capabilities at external suppliers. Strategic support agreement requirements will be monitored as part of obsolescence management.

The SKAO shall establish service level performance requirements for all externally sourced support needs of the observatory, including warranty support. Service level assignments shall address requirements essential to telescope operational availability, whilst minimising cost. Assignments shall consider the economic trade-off.

Suppliers engaged through service level agreements (SLAs) shall be tasked for sustaining a specified level of service. Supplier SLA compliance reporting shall be on an exception basis and the duty of
notifying, logging, and instituting corrective action shall, in the first-place, rest with the supplier’s quality management system. The SKA will perform acceptance testing and inspections to ensure the supplier delivers the quality required.

SLAs intended to bridge the establishment of SKA support capabilities shall include delivery of support data, training, and other support products required to enable SKAO ongoing support. Contracted original equipment manufacturer (OEM) repair activities and SLAs will be managed by the support personnel. SKA monitoring of service-level compliance will reference to status and events logged by the telescope manager.

6.4.6.11 Engineering Management System

The engineering management system (EMS) is a system that will be used to manage and refine the telescope's maintenance plans. The EMS is also an integral part of regular weekly meetings to discuss the status and problem areas. A single cloud-based system will show a dashboard that reflects the telescopes availability and maintenance tasks to be performed.

Jira tickets and Job cards will collect data that will be used to calculate the KPIs that will be used to:

- manage the operational availability of the telescopes;
- improve the problem areas;
- review and optimise the maintenance plans; and
- determine staffing utilisations and needs - engineering operations management software will be required to support the operations and maintenance of the SKA telescopes.

The EMS is a collection of software tools that are required to operate as an integrated set. It includes a configuration database (Enterprise Bridge, or eB, a document management software package from Bentley) and a problem reporting and tracking system (§6.4.8) that will be provided by the project. A SAFe agile project will also develop additional interfaces and requirements. The data and documentation required will be developed during the construction phase.

The EMS will serve as an integrated operational information system for the Observatory, providing the following functionalities:

- configuration management (§6.4.6.13);
- maintenance and support planning (maintenance base);
- technical publication development (documentation and training base) (§6.4.6.14);
- creation of an operational baseline;
- problem reporting and tracking (§6.4.8);
- maintenance activity management;
- warehouse/stores support;
- OEM repair and SLA support;
- serial number tracking;
- availability monitoring (§6.4.6.1);
- condition monitoring (§6.4.6.5); and
- training management.
The system will be managed by SKAO engineering operations and will consist of:

1. Problem reporting and tracking system (PRTS) - a ticketing system for logging and tracking of problems and failures (§6.4.8).
2. Logistic support analysis database (LSA) - a database compatible with MIL-STD-1388-2B [RD13] to develop the product breakdown structure (PBS), FMECA, task summaries and detailed support requirements. It will also include a Monte Carlo simulation model to predict and quantify the support requirements.
3. Configuration management database – eB will be used as a configuration control database.
4. Data module content management system - a data module manager compliant with S1000D [RD14] to manage the data modules.
5. Training manager - a training management database to manage the training requirement and keep records of personnel and their competencies.
6. Computerised maintenance management system (CMMS) – a failure and planned maintenance database. It will also collect downtime and repair data for all maintenance activities.
7. Interactive electronic technical manual/publications (IETM/P) viewer - an online viewer, compliant with S1000D, to view electronic manuals, training and procedure information. It will also include a review capability to enable the review of documents during commissioning and initial training.
8. Application – an offline application that will allow the user to view and add content offline.
9. Documentation editor – an XML editor used to prepare S1000D-compliant technical content for the IETM/P.
10. Illustration software – a vector image editor which will be used to edit and draw illustrations and to prepare S1000D-compliant technical illustrations for the IETM.

The EMS will have interfaces to the Observatory wide systems, including observation management, and telescope monitoring and control. An interface to observation planning will allow for science observing to be scheduled together with the maintenance work (see §6.4.4.5.2 and §6.4.4.7). A detailed description of the architecture, requirements, and interfaces is in [RD15] and [RD16].

![Figure 26. Usage of the engineering management system across the three SKA sites.](image-url)
The SKA EMS will be supported and maintained as an engineering operations-critical capability for the Observatory. The high-level relationship between GHQ, SKA1-LOW and SKA1-MID operations for use of the EMS is shown in Figure 26.

GHQ Engineering Operations is responsible for developing the base information (i.e., configuration, maintenance, documentation, and training). This information will be provided to the MID and LOW operational groups for execution. The MID and LOW engineering groups are also responsible for providing feedback and updates to the base information.

6.4.6.12 Software Support

As for other observatories, the SKA software suite will continue to evolve during the lifetime of the telescope. This is necessary to support the science and engineering operations of the observatory and the type of work will include:

- new and improved diagnostics;
- minor new engineering and science functional and non-functional requirements (e.g., new observing modes, changes in telescope configuration, adapting to different scientific priorities, usability improvements)\(^{21}\);  
- addressing errors in the codebase; and  
- supporting expert users in understanding the algorithms in the codebase.

The presence of software engineers at the telescope sites will be minimised with software and firmware maintenance performed remotely and tested off-line, where possible. This includes planned updates and upgrades as well as unplanned maintenance (e.g., fixing bugs and errors). Software maintenance activities include, but are not limited to:

- periodic and non-periodic software maintenance activities;  
- re-installing operating systems;  
- loading and initialisation of software/firmware on components;  
- roll-back and roll-forward of software versions;  
- software configuration and version control; and  
- testing of software functionalities.

There will be a limited need for technical support on-site for swapping and configuring LRUs, but the systems will be constructed to avoid single points of failure, allowing this work to be normally scheduled in advance as a maintenance task.

Whenever possible, the use of engineering subarrays will be maximised so that software testing, patches, and updates can be executed on an isolated operational system before rolling out and deploying on the full system. This allows the science programme to continue largely uninterrupted on the remaining resources of the telescopes while testing is being carried out.

6.4.6.12.1 Software and Computing Staffing and Management Structures

It is important that the Observatory has suitably trained staff to support its functions at the end of construction, so the transition from construction to operations is managed and occurs as smoothly as possible and is practicable. These operational staff numbers are based on pre-construction consortia estimates for steady-state operations and cross-checked in discussions with SKA precursor facilities, and comparison against comparable telescopes (notably the ALMA integrated computing team).

\(^{21}\) It is assumed that major software upgrades will be funded, managed and delivered through the Observatory Development Programme or from other sources outside the Observatory operations budget.
However, the specific roles outlined by the pre-construction consortia have been adapted to develop a coherent computing and software team.

The staffing level is planned to ramp up during construction in advance of these duties. It is also anticipated that there may be a significant transfer of construction staff to operational staff, particularly in the host countries, and this will have to be actively managed. The staffing complement in computing and software at the GHQ and at each of the two telescopes sites, who are based at the science operations centres, is listed in Table 31 and Table 32.

Table 31: Role descriptions and the number of staff supporting computing and software at the GHQ. Line management of these staff is shown in Figure 28.

<table>
<thead>
<tr>
<th>Role</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head of Computing &amp; Software</td>
<td>GHQ</td>
<td>Responsible for all SKA Observatory computing and software activities. The role guides the use of computing and software resources to achieve the project mission and leads the telescope IT responsibilities.</td>
<td>1</td>
</tr>
<tr>
<td>Lead Software Architect</td>
<td>GHQ</td>
<td>Responsible for the overall SKA software high-level design choices, technical standards, coding standards, tools, and platforms.</td>
<td>1</td>
</tr>
<tr>
<td>Head Software Architects</td>
<td>GHQ</td>
<td>Responsible for software high-level design choices and solution development. One each for data processing, observation management, controls, pulsar systems, networks, SRCs.</td>
<td>6</td>
</tr>
<tr>
<td>Software Quality Engineer</td>
<td>GHQ</td>
<td>The Software Quality Engineer acts as the Technical Lead and is responsible for maintaining and updating the SKA software engineering process documentation and configuring and managing the software support tools.</td>
<td>1</td>
</tr>
<tr>
<td>Computing Infrastructure Lead</td>
<td>GHQ</td>
<td>Lead the platform team to define computing platforms that are suitable for the needs of the SKA, with a particular emphasis on the state-of-the-art systems that will be required for the science data processor and the pulsar search systems.</td>
<td>1</td>
</tr>
<tr>
<td>DevOps Development Engineers</td>
<td>GHQ</td>
<td>Develops and supports the continuous integration, testing and deployment systems.</td>
<td>2</td>
</tr>
<tr>
<td>Tango Core Support</td>
<td>GHQ</td>
<td>Define changes needed to the Tango core to support the needs of the organisation. This role implements changes to Tango core software and feeds them upstream to the Tango collaboration.</td>
<td>1</td>
</tr>
<tr>
<td>Network and IT Security Specialist</td>
<td>GHQ</td>
<td>Responsible for supporting networks and IT security.</td>
<td>1</td>
</tr>
<tr>
<td>Controls Team</td>
<td>GHQ</td>
<td>Engineers specialising in control systems.</td>
<td>3</td>
</tr>
<tr>
<td>Data Processing Software Engineering Team</td>
<td>GHQ</td>
<td>Supports the data processing services including algorithms, execution frameworks, workflows/pipelines.</td>
<td>9</td>
</tr>
<tr>
<td>Business Processes and Web Systems</td>
<td>GHQ</td>
<td>Developers supporting business process tools based around databases with web front ends and appropriate business logic. Includes observation</td>
<td>6</td>
</tr>
</tbody>
</table>
Software Engineering Team

<table>
<thead>
<tr>
<th>Role</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution Train Engineer</td>
<td>GHQ</td>
<td>Manages the software release trains at the solution level.</td>
<td>1</td>
</tr>
</tbody>
</table>

**TOTAL 33**

Table 32: Role descriptions and the number of staff supporting computing and software in each of the SKA1-LOW and SKA1-MID telescopes in Australia and South Africa, respectively. Line management of these staff is shown in Figure 29.

<table>
<thead>
<tr>
<th>Role</th>
<th>Location</th>
<th>Description</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head of Computing &amp; Software</td>
<td>AUS &amp; RSA</td>
<td>Responsible for all SKA Observatory computing and software activities in a particular SKA host country. The role guides the use of computing and software resources to achieve the project mission and also leads the telescope IT responsibilities.</td>
<td>1</td>
</tr>
<tr>
<td>Controls Team</td>
<td>AUS &amp; RSA</td>
<td>Software engineers specialising in and responsible for control systems of the SKA telescopes.</td>
<td>7</td>
</tr>
<tr>
<td>Data Processing Team</td>
<td>AUS &amp; RSA</td>
<td>Specialists responsible for data processing matters (covering PST, PSS, and SDP) for the SKA telescopes.</td>
<td>12</td>
</tr>
<tr>
<td>Platform &amp; Networks Team</td>
<td>AUS &amp; RSA</td>
<td>Supports platform development and networks for the SKA telescopes.</td>
<td>12</td>
</tr>
</tbody>
</table>

**TOTAL 32**

Figure 27. Computing and software leadership roles at the SKA Observatory. High-level leadership and planning to support the computing and software of the SKA Observatory will be delivered by this team. Dashed lines indicate that the relationship is functional and not a line management one.
It is anticipated that the computing and software teams across the observatory will form a planning and leadership team as depicted in Figure 27. This group represents the executive delivery team for computing and software for the SKA Observatory (hence, the dashed lines in the figure represent functional relationships and not line management). Regular coordination meetings, co-opting other staff as necessary, are anticipated. In addition, long-term planning of the software and computing of the observatory will be led by this group, as will high-level engagement with the operations group on the development roadmap.

Since the three largest bodies of software (the telescope manager, science data processor and the pulsar search engines) plan a large shared codebase with different configurations for the two telescopes, for the purposes of planning, it is assumed that support for common codebase items will be located at the GHQ. The line management of these staff and the group structure is depicted in Figure 28.

It is planned that the line management of the teams at the telescope host countries is independent and local, with the line management and reporting flowing through each Telescope Director to the director of operations at GHQ. The line management of these staff and the group structure is depicted in Figure 29.
Note that the Scaled Agile Framework (SAFe®) for software development is the chosen methodology within the SKA Observatory and will be prominent during the development and implementation phase of construction. This methodology will persist into the operations phase.

6.4.6.13 Configuration Management

Operational configuration management principles and practices will be developed during the construction phase, based on the design data pack and installation records, and then maintained throughout the operational phase. It will consist of data relating to the telescopes, infrastructure, and support equipment. The as-built configuration will be recorded during construction.

All configuration changes will be managed and traced through the operational life cycle by means of an engineering change proposal process. The change management relationships are shown in Figure 26. The SKAO configuration management requirements are described in the SKA configuration management plan [AD3]. The configuration management system (eB) is part of the EMS.

6.4.6.14 Technical Data and Publications

Technical publications will be developed to provide the information needed for personnel to perform specific tasks for operation and maintenance. It will be based on international best practice and will complement training material development. Technical information will be managed and developed to provide Interactive electronic technical manuals/publications (IETM/P).

The logistic support analysis will result in a “locations” structure based on the product breakdown structure. This structure will define the locations and positions for all maintenance items (also referred to as slot positions in a maintenance structure). The locations structure will contain all hardware and software items down to the required maintenance level.

A common source database will contain all the maintenance and technical publication data. The data modules, in xml format, will be the prime source for the IETM/P. SKA support software systems will have access to the xml information. The xml format will provide the software products to make full use of the structured information and ensure an integrated system to operational personnel.

Operating and support task requirements will be developed to identify the technical information requirements and a data module requirement list (DMRL). This process will commence early in the construction phase. Developed operating and support procedures will be evaluated and matured as part of SKA1 AIV and commissioning.

6.4.6.15 Supply Support

Spare parts and consumables will be acquired to meet operational and support requirements at each stage of telescope deployment. Stocks used during commissioning will be replenished to ensure adequate stock levels for supporting the telescopes during full operation. It is assumed that initial spares and consumables (including any strategic spares requirements) will be delivered to meet the operating and support requirements at each stage of telescope deployment. Relevant spares or consumables stocks consumed during commissioning will be replenished/restored to operational stores before the conclusion of construction activity. The number of spare parts and consumables required will initially be calculated as part of the LSA by simulation/modelling. Stock levels will be allocated based on criticality and the out-of-stock probability. Selective strategic stocks will be acquired to optimise operations costs over the Observatory’s life cycle and to mitigate supply chain
risk. Strategic spares requirements will be determined by obsolescence management and by economy of scale considerations.

Critical parts and items with a long lead time will be obtained during the lifecycle of the observatory to reduce the risk of outages. The requirements for strategic components will also be determined by consideration of ageing and cost. The following will be used to determine how many and which spare parts must be obtained:

- support agreements;
- impact of item failure on availability;
- estimates of failure rate, durability, and service life;
- scale benefits and cost; and
- obsolescence risks.

Different levels of maintenance are identified from the simplest, organisation level (O-level) undertaken close to the location of the equipment, through intermediate level (I-level) undertaken back at the EOC, to depot level (D-level) undertaken at specialised centres.

Organisational-Level maintenance is performed on the telescope at the various locations. The following are examples of O-level maintenance locations for the SKA: the Karoo Array Processor Building (KAPB) at Losberg for the SKA1-MID telescope; the low-frequency aperture array (LFAA) field stations and repeater stations; and the science processor centres. O-Level maintenance can include corrective and preventive maintenance.

Corrective maintenance at I-Level is performed on LRUs removed at O-Level and brought to the EOC. It is performed by the removal and replacement of shop replaceable units (SRUs). Complex I-Level preventive maintenance will also be performed on LRUs removed at O-Level.

Depot-level maintenance will be performed at specialised maintenance centres (off-site). Corrective maintenance at D-Level is performed on LRU and SRUs from O- and I-Level maintenance facilities. Preventive maintenance at D-Level will be performed by executing specialist maintenance on equipment removed at O-Level and maintenance that cannot be performed at I-Level. D-level maintenance locations may include Perth for the SKA1-LOW telescope and Cape Town for SKA1-MID.

O-level stores will provide LRUs and consumables that will be used on-site. All items defined as spares at O-level shall be interchangeable with no item-level calibration, tuning or alignment required. I-level stores shall provide LRUs to the O-level and SRUs, as well as consumables required for I-level maintenance. All items defined as spares at I-level shall be interchangeable with installed items with a minimum of calibration and aligning required. If required, alignment and calibration procedures shall be developed as part of the technical publications. D-level stores shall provide long-lead LRUs, SRUs, and components. D-Level supply support shall also provide LRUs and SRUs to the I-level and O-level maintenance facilities.

Operational stock levels of spares and consumables will be optimised and maintained by a programme of replenishment and by monitoring demand rates, turn-around times for repairable spares, and supply lead times. The accountability of all items and consumables will be controlled using item orders and delivery notes transaction logs. The electronic signatures on receive and dispatch notices will ensure item accountability.

The authorisation and routing of supplies are indicated in Figure 30. It applies to the supply of new items and repaired items.
Selective strategic stocks will be acquired to optimise operations costs over the life cycle and to mitigate supply chain risk. Strategic spares requirements will be determined by obsolescence management and by economy of scale considerations.

6.4.6.15.1 Support, Test Equipment, and Tools

The support and test equipment (S&TE) requirements for the various maintenance levels are to be determined during the LSA process — accounting for the support needs of the production baseline equipment. S&TE must be suitable to operate in the telescope support environment, at the applicable levels of support. Test jigs and equipment used during development and integration will be utilised and standardised as far as possible. The use of commercially available equipment for meeting operational support and test requirements will be prioritised. Requirements for any specialised S&TE will be motivated by the LSA and by a cost/benefit trade-off.

Initial S&TE will be delivered to meet the operating and support requirements of each stage of telescope construction. Suitable support equipment must be procured, and support equipment operating procedures developed. The complete telescope S&TE requirements will be established for the commencement of operations.

6.4.6.15.2 Packaging, Handling, Storage, and Transportation

Spares and items removed from the telescope for service or repair will be protected from damage during operational handling, storage, and transportation. A SKA packaging, handling, storage and transportation standard and procedures will be developed.

6.4.6.16 Obsolescence Management

The design authority is responsible for the design that takes obsolescence into account. A modular approach with clearly functional demarcations and detailed interface specifications is of the utmost importance. All potential obsolescence risks and alternative mitigation strategies will be evaluated during the construction and equipment selection process.

The operations group will be responsible for compiling and managing an obsolescence risk register as part of the engineering operations activities. This register will be developed and maintained for the
total lifetime of the telescopes. It is also important to address obsolescence in the contract specifications and SLAs.

The telescope design and support concept will be continuously assessed for obsolescence-sensitive items and obsolescence risk. Obsolescence assessments and reporting will consider all critical items, including spares, skills and specialised support and test equipment. Assessments will focus on custom-design items, rapidly evolving technologies, and products lacking backward compatibility with the installed base.

Strategies for management of obsolescence will be consolidated at system level and will include preemptive action to cost-effectively minimise obsolescence risk to operational availability and the cost of ownership. Mitigation strategies may include stockpiling, guaranteed long-term support, and technology refresh.

6.4.7 RFI Management during Operations

RFI can be one of the most detrimental effects to radio astronomy. Effective RFI management during the operations phase will aim to avoid its growth and minimise its presence at the SKA sites, across the relevant frequency range as specified in the high-level policies [AD2]. When avoidance of RFI is not possible, the next best thing is to have as complete an understanding of the nature and characteristics of the RFI as possible. A plan for RFI management can be developed by answering three questions: (1) What do we need to do? (2) Who will do it? (3) How can we do it?

6.4.7.1 RFI Management Functions

To answer the first of these questions we define what functions need to be implemented. These are:

- **Policy and procedure development and enforcement**: Policies and procedures to control and mitigate RFI on the Observatory sites and their enforcement. Decision making on RFI issues at different levels within the observatory.
- **Measurement, characterisation and troubleshooting**: Implement a site RFI monitoring strategy. Post maintenance RFI testing for compliance. RFI characterisation.
- **Spectrum management**: RQZ administration. International spectrum management. Interactions with industry.

Policies and procedures to enforce, control, and mitigate RFI on the Observatory sites need to be developed. Even though each site entity (i.e., CSIRO for Australia and SARAO for South Africa) will be responsible for maintaining the radio-quiet zone (RQZ) on their sites, the SKA should have its own independent mechanisms in place to characterise the RFI environment of its telescopes, as that will directly impact the quality of the science data. The monitoring strategy will include:

- fixed RFI monitoring stations;
- routine mobile RFI monitoring campaigns;
- RFI investigations; and
- the use of engineering subarrays for RFI monitoring campaigns.

The last point speaks to the fact that the most sensitive RFI monitor on-site will be the telescopes themselves. Scheduling of specific, small, engineering subarrays will occur as part of the RFI monitoring campaigns. Techniques for software level flagging of RFI in signal and data processing will be pursued.
Equipment and telescope components may enter the telescope site either through delivery from a manufacturer or after they have been repaired at the EOC. In the latter case, the physical characteristics may have changed and compromised its RFI shielding. All such equipment will be checked for RFI compliance at the EOC before being delivered to site, and they will be issued with a permit and/or certificate of compliance before being allowed onto the site.

6.4.7.1.1 Spectrum Management

The regulatory aspect of RFI management is dealt with by spectrum management, a highly political discipline with interactions between national administrations, commercial, and scientific groups. It deals with all RFI that is generated outside of the RQZ and detected by a SKA telescope (e.g., satellites, aeroplanes).

If the source is terrestrial in origin, the RQZ regulations would apply and the site entities and national stakeholders would need to manage and deal with the situation. As a major stakeholder, the SKA should have some oversight of the process, although the responsibility remains with the host country. The frequency range protected by the RQZ is between 100 MHz and 25.4 GHz for both Australia and South Africa.

Sources that are airborne or spaceborne are out of the control of the RQZ regulations and must be managed through international spectrum management, through the ITU-R Radio Regulations.

The Observatory’s spectrum management strategy involves active participation in the governance and administrative structures that control radio frequency utilisation worldwide. SKA comprises the two most sensitive radio-telescopes ever constructed in their frequency range. The locations of these two instruments have as much national regulatory protection as can be achieved on a populated landmass. Moreover, the frequency bands over which the SKA1 telescopes operate contain a number of internationally protected bands within which radio-frequency interference from intentional transmitters, wherever they may be, is regulated. The spectrum management strategy will be to drive the management of radio frequency interference over the entire spectrum of radio-astronomy interest, not just the protected bands.

SKAO participates, through its member states, the host country radio-astronomy institutes, the radio-astronomy co-ordinating bodies, its community of domain experts, and its own internal resources, in radio frequency spectrum management efforts worldwide. This is done to protect the interests of the scientific community exploiting the capabilities of the SKA telescopes and more widely. This latter is fitting for the globally dominant radio-astronomy entity that is the SKA. The SKA spectrum management activity is led by the spectrum manager, guided by a spectrum management group including engineering, legal, and policy staff, and works closely with SKA partners and national/international bodies.

6.4.7.2 RFI Management Organisational Structure

The management structure for dealing with RFI issues is depicted in Figure 31. There are three levels, starting with RFI groups at each telescope site, another group at the GHQ, and then a high-level RFI committee composed of the SKA director of operations, the science director, and the two Telescope Directors.
Day-to-day operations and the majority of RFI related issues will be managed by the RFI groups at the two telescope sites. Issues include (but are not limited to): maintenance, RFI acceptance and compliance testing, RFI monitoring, and RFI investigations. The telescope RFI groups are responsible for monitoring and controlling the RFI environment of the telescopes.

The SKA RFI group is responsible for defining and implementing RFI management strategies. Its primary role is in the area of development of policy and procedure. Furthermore, its remit will include engagement with the site entities responsible for the administration of each RQZ, as well as other external stakeholders.

The RFI committee is a high-level group. It will be convened as required to address issues that cannot be resolved at any of the lower levels. Normally issues will be escalated by the SKA RFI group to the RFI committee. The RFI committee will also be responsible for reviewing and approving RFI policies and strategies.

The telescope RFI groups will meet regularly (monthly or more frequently, as required). The SKA RFI group will meet quarterly and include the chairs (and other representatives as required) of the telescope RFI groups. The RFI committee meets on an ad hoc basis, but at least once a year to deal with any high-level matters.

6.4.7.3 Roles and Responsibilities

The high-level responsibilities of the SKA Observatory and the host countries are briefly described in §6.2.2, including those with respect to maintaining RFI-quiet telescope sites.

It is anticipated that CSIRO and SARAO will execute the majority of these responsibilities on behalf of the host country. With the start of the construction phase of the project, they shall be responsible for the implementation and enforcement of applicable RFI policies and procedures on each site. This shall include, but will not be limited to, monitoring and enforcement of permits, notices and certificates of compliance, which shall be issued on presentation of acceptable measurement and analysis reports.
that comply with the necessary measurement, and other relevant, standards. As appropriate, they will undertake on-site measurements to monitor the integrity of the on-site RFI environment and be responsible for the management of the external RFI environment in terms of relevant legislative and regulatory measures. Measurement resources and capacity may be made available to SKAO, or their contractors, subject to an appropriate agreement.

The SKAO will be responsible for monitoring its own telescope RFI emissions and maintaining those within agreed limits. It will monitor, measure and analyse the RFI environment of its telescopes and ensure that any equipment that returns to site is appropriately RFI tested and qualified. The SKA will issue appropriate documentation on behalf of contractors and visitors that need to come onto the site on behalf of the SKA. If appropriate, such documentation will contain measurements that demonstrate compliance.

In summary, the responsibilities are:

**Host Country Responsibilities**
- Spectrum management in host countries.
- Review and approve EMC/EMI control plans for all telescopes.
- Issue, inspect, and check RFI permits and certificates of compliance for all telescopes.
- Issue non-compliance reports and certificates for all telescopes and contractors.
- Scans, data analysis, and site characterisation for all instruments.
- General site induction.

**SKA Observatory Responsibilities**
- Spectrum management (for international bodies).
- Review and accept EMC/EMI control plans for SKA1 contractors.
- Inspections and compliance to permits and certificates of compliance for SKA contractors.
- Submit documentation to allow contractors to access the site for SKA-relevant activities.
- RFI testing (off-site and on-site) and verification.
- Scans, data analysis, and site characterisation for the SKA.

Although these responsibilities will persist beyond construction and into operations for SKA-LOW, the situation for SKA-MID is different. SKA will take responsibility for the SKA-MID site following the integration of MeerKAT into the SKA-MID telescope (so nominally, before the end of the construction phase of the project). At that time, SKAO will become responsible for implementation and enforcement of applicable RFI policies and procedures for the Karoo site. SARAO may make resources and capacity available to SKAO, or their contractors, through an appropriate mechanism to implement and enforce applicable RFI policies and procedures on behalf of the SKAO and undertake appropriate RFI monitoring and measurement as required. SARAO shall continue to be responsible for the management of the external RFI environment in terms of relevant legislative and regulatory measures and shall require close cooperation and insight into the internal RFI environment and its relevant stakeholders.

6.4.8 Problem Reporting and Tracking

There shall be a problem reporting and tracking system (PRTS) in place to track and manage the issues, faults, and other investigations that are being worked on throughout the Observatory. The PRTS will be based on a ticketing system (such as Jira, a software product from Atlassian) and will follow a
workflow similar to that illustrated in Figure 32. All problems identified during the construction and operational phases will be reported and logged by means of the PRTS as a measure to effectively assign and track problem resolution.

When an issue arises, on any telescope system (hardware or software) then a ticket can be opened by a member of staff providing a description of the problem. It is likely that the Telescope Operator will be the main generator of tickets for issues and faults that arise in the operational system. Operational problem notification to the Telescope Operator shall be automated in the form of telescope statuses, warnings and alerts/alarms presented by the telescope control, management and monitoring systems. These events will be logged with the nature of the event automatically described from the error condition and/or the error/warning code. Events that interrupt or degrade the operation of the telescope will result in a PRTS ticket issued by the Telescope Operator.

There will be a Telescope Operator for each telescope at all times to ensure that observations are proceeding successfully, and to react to faults (or other events) if and when they occur. The system will automatically notify the Operator when a fault does occur. It will also be the responsibility of the Telescope Operator to monitor the data quality flags (as reported by the pipelines).

When a fault is detected, the Operator will decide whether to:

- allow observing and data processing to continue;
- abort the observation and repeat; or
- stop all observing to chase down the fault.

The particular course of action chosen depends on the severity and impact of the fault. In the event of a fault, the Operator must:

1. Be informed that a fault has occurred.
2. Identify the nature and cause of the fault.
   - A database of currently open and closed faults, and their resolution (or otherwise), should be accessible for the Operator’s information.
3. Attempt limited troubleshooting, depending on the nature and severity of the fault.
4. Isolate the faulty system from the rest of the telescope if this is not done automatically.
   - For example, if a single dish or beam within a subarray fails then, depending on the severity and nature of the fault (and the type of observation), it could be automatically isolated from the rest of the subarray and observing should continue with the remainder of resources in the subarray.
   - QA alerts should inform the Operator whether there is any significant degradation to the data compared to expectations or previous performance.
5. Continue observing if possible.
   - If it is not possible to continue with the present observation, then the next feasible observation should be executed. In most cases, this should occur automatically, although following a fault it is prudent for the Operator to grant permission to execute the observation.
   - The telescope status will be updated automatically once a serious fault occurs so that the next highest priority, available and feasible scheduling block can be identified and executed.
At this point, the Telescope Operator will open a PRTS ticket describing the fault: The Operator will:

1. Annotate the fault report with information that should contain:
   - A concise narrative describing the fault, its characteristics and the impact to observations not already described by the automated log reports.
   - Any corrective actions taken.
   - The amount of observing time lost, if any.
2. Update the shift log tool with the status of the observation affected by the fault, with a link to the PRTS ticket filed by the Telescope Operator.
   - Statuses reported for the observation may include: GOOD, BAD, QUESTIONABLE, or JUNK.
3. Notify appropriate personnel of the fault if necessary.
   - In the case of a severe (i.e., time-losing, or risk of component failure) fault, the Telescope Operator should attempt to notify appropriate personnel.
   - Operations support staff should be regularly monitoring the logs and reports from the telescopes, identifying any issues that need to be elevated in priority.
   - It is the Telescope Operator’s responsibility to provide a clear and concise fault report that will allow local operations support staff to understand the problem encountered and respond in a timely manner.

The PRTS shall provide in-progress tracking information for open issues. It shall provide access to PRTS process records of all open and closed-out issues.

The CMMS will support the operational PRTS in accepting maintenance-related issues assigned to CMMS work orders. The maintenance management function will provide problem resolution maintenance in-progress and close-out status to the operational PRTS.

Problems related to telescope failures will be assessed for root cause and corrective action requirements, making use of the failure recording analysis and corrective action system (FRACAS). The PRTS, CMMS, and FRACAS form part of the engineering management system described in §6.4.6.11.

Each day, an operations meeting is held where new faults issued in the past 24 hours will be triaged and assigned to the relevant groups. The purpose of this meeting is to quickly identify the nature of the problem (e.g., software, electrical, mechanical, etc) and assign ownership of PRTS tickets to the relevant group. The Head or Lead for each of these groups may then choose to delegate the issue to someone in their group for detailed investigation and resolution.

A separate meeting (maybe weekly, TBD) will be held where all active PRTS investigations are reviewed and discussed (this is not shown in Figure 32).
6.4.9 Working on Site

6.4.9.1 Site Security

The SKA-MID site will have 24/7 security coverage with personnel staffing five security guard huts securing the NRF-owned land and the EOC at Klerefontein. Two of these security guard huts are located at the SKA site complex which has been declared a National Key Point by the South African Government. The South African Police Service undertakes regular patrols to inspect the National Key Point.

Security teams will monitor all traffic entering and exiting the SKA-MID site and the team is also responsible for undertaking breathalyser tests so that no one accessing the site is under the influence.

Figure 32. Problem reporting and tracking workflow.
of alcohol. The dishes along the spiral arms and supporting infrastructure in the spiral arms are secured with perimeter palisade fencing.

There are no plans for active security at the Murchison Radio Observatory where the SKA-LOW telescope will be located.

### 6.4.9.2 Presence on Telescope Sites

A guiding principle for the SKA design has been to minimise the number of operational staff working on the sites. This is motivated by:

- the fact that human activity significantly increases the amount of RFI on the sites;
- the operational need to minimise travel and accommodation costs; and
- the fact that both telescope sites present hazardous environmental conditions.

For these reasons, it is desirable to minimise the human footprint on the sites.

The maintenance strategy (§6.4.6.3) specifies that the normal procedure, in the event of a hardware fault in the field, will be to replace the faulty LRU with a spare and then to repair the faulty unit at a facility elsewhere (either at the EOC or with the OEM). Repair of hardware faults in situ is not presently envisaged unless that repair can be achieved quickly, efficiently, and safely.

### 6.4.9.3 Commissioning and Delivery of New Systems and Instruments

The procedure that identifies the steps for the hand-over of systems to the Observatory will be augmented, if necessary, to cover special needs for the SKA. This includes a procedure of how commissioning teams hand-over systems and how the Observatory accepts the system. Any new system that is delivered to the Observatory shall include:

- Operation and maintenance manuals;
- System transfer documents (including the commissioning report that will remain the reference document for the system performance maintenance on the Observatory);
- The full as-built documentation, including optical, mechanical, and electrical drawings;
- A procedure to verify the operational system performance on-site;
- A procedure to verify the operational system configuration.

### 6.4.9.4 Infrastructure Support

It is anticipated that maintenance support of the infrastructure will be contracted out, and it is further assumed that CSIRO and SARAO will manage those contracts for SKA1-LOW and SKA1-MID, respectively. The skill sets required are not observatory/telescope specific and therefore may be cheaper and more effectively procured externally. Moreover, obsolescence of skills is also avoided.

### 6.4.9.5 Site Communications

Voice communications will be required in a variety of circumstances. Some examples are:

- **Routine, on-site communications:** Workers in the field needing to communicate with personnel elsewhere on the site, for example regarding vehicle movements or requesting technical information to enable the work at hand to be carried out.
Routine, off-site communications: Workers at the CPF needing to communicate with colleagues off-site, for example, regarding the movement of spares between the EOC and the site; and personal communications.

Emergency, on-site communications: Workers in the field needing to communicate with personnel elsewhere on the site, for example, to report an accident.

Emergency, off-site communications: Workers on the site needing to communicate with colleagues and external agencies off-site, for example calling the Royal Flying Doctor Service in Australia.

In order to provide for these situations, a variety of capabilities will be implemented, as follows:

1. an on-site telephone system, connected to the public telephone network;
2. an RFI-compliant, on-site communications system for routine operational use. Usage of this system should be minimised, but there will be many situations in which it is impossible or inadvisable for workers in the field to get to the nearest telephone;
3. an emergency communications system, capable of on-site and off-site communications, which need not be RFI-compliant. This system must be available on-demand to ensure that emergencies can be swiftly reported whenever they occur; and
4. an accident detection system, to provide notification when a crew in the field ceases being active and is incapable of reporting.

6.4.10 Interaction with the User Community

6.4.10.1 User Support

SKA users\footnote{SKA users comprise scientists who are planning, proposing or have accepted SKA projects, as well as those with access rights to SKA science data products.} will be able to access a range of support throughout every stage of their project, from the initial planning stage to the delivery of the final data products. Users will be informed by an extensive documentation set that will guide them on all aspects of the SKA Observatory operations that are applicable to them. SKA operations will be responsible for providing and maintaining this documentation which can exist in various formats, e.g., PDFs, web-based guides, and FAQs. All information pertinent to proposals and projects, including access to data processing platforms, will be provided through the SKA Science Gateway, accessible from the web pages of the SRCs as well as the SKA home page.

Approved projects will be assigned a “friend of project” (FoP), selected from the pool of science and operations support staff from across the whole Observatory. The FoP will serve as the point of contact for PIs and Co-Is to raise project-specific queries (e.g., observation design and data quality). FoP status persists after a project’s data is delivered to an SRC. Queries on specific projects that generate tickets via the Helpdesk system (described below) will alert the FoP automatically.

Registered SKA users requiring additional assistance with any aspect of their SKA project, or with a need to communicate with the SKA Observatory for any reason, will be able to do this via a single Helpdesk facility, accessible to all users through a web browser. The Helpdesk will comprise a publicly accessible, categorised “knowledge base” (or FAQ) and have the functionality for registered SKA users to submit requests for support on specific issues concerning their projects (i.e., either observing programmes or data quality) or proposals, report software bugs, problems or faults, make general enquiries, submit requests for director’s time, project change requests, and provide feedback to the Observatory. Users will be able to provide a description of their queries (including important details
such as project codes), add necessary attachments, and select the category and subcategory that best matches their query.

The Helpdesk will be supported by both SKA Observatory and SRC staff who will each contribute a fractional FTE (fraction will depend on individual roles, Helpdesk demand, and support agreement between the SKAO and the SRCs) to the Helpdesk as part of their roles. In order to efficiently assign and answer Helpdesk tickets, Helpdesk staff will be divided into a series of virtual departments, reflecting the main themes of the anticipated Helpdesk tickets (e.g., proposals, gaining access to SRC resources, SRC data reduction, policy, proposal change requests). As part of this department structure, we envisage a general department managed by a SKAO staff member (requiring a total dedicated 1 FTE). They will manage the membership of the other departments and assign tickets that fall outside of the department categories.

Helpdesk tickets will be initially assigned to the user-selected department (based on their initial categorisation) and the Department Manager will then either accept the ticket or reassign it to a more appropriate department. Helpdesk tickets without a clear category (as determined either by the user or department manager) will be directed to the general Helpdesk department at the SKA Observatory for assignment. Once assigned, Helpdesk tickets will be investigated, and, depending on the severity, the assignee may be able to respond with an immediate solution (or point the user to the knowledge base for common questions and answers) or require some iteration with the ticket reporter and/or internal staff. In some instances, the Helpdesk ticket might highlight an issue with a telescope or data processing that may require an internal SKA ticket to be submitted by the Helpdesk staff. A summary of the Helpdesk ticket workflow is provided in Figure 33.

Initial responses to Helpdesk tickets will be provided within two business days. The total time taken to close Helpdesk tickets will be closely monitored and department managers will be alerted to and have the ability to increase the priority level of, tickets that have been open for more than TBD days. The Helpdesk standards of service (response time and time to close a ticket) and user satisfaction will be assessed regularly through Helpdesk ticket statistics and user feedback.

Every effort will be made to plan for the anticipated higher level of Helpdesk demand in the first years of operation, especially in the lead up to the first few proposal deadlines. In order to mitigate some of this demand, we intend to begin operations with an extensive Helpdesk knowledge base, drawing on the experience of commonly asked questions at other major radio observatories and capture those asked through other SKA forums. In the lead up to proposal deadlines, an “emergency” Helpdesk team will be assembled to ensure fast response time and a smooth proposal process for all users.

In addition to the routine user support model provided through the extensive documentation set, FoP assignment, and the Helpdesk, the SKAO will embark on a community training regime ahead of the first proposal deadline (and as required). These training sessions will familiarise the community with the capabilities of the SKAO and provide training on the tools needed to plan and propose a project. The details of these training sessions are still TBD but may consist of a number of in-person sessions, supplemented by instructional videos in order to reach the entire community. Questions raised during these training sessions will be a valuable resource for informing potential topics to be included in the Helpdesk knowledge base.
6.4.10.2 Advisory Committees

The SKA Observatory anticipates a number of committees by which its users can provide input. This will include a users’ committee to solicit input from SKA users on different aspects of the Observatory’s science and operations activity, including but not be limited to issues concerning the SKA science programme, proposal and project management, data quality, the SRCS, and user support. Such a committee will hold regular annual meetings and provide their advice through a report to the SKA DG (or their delegate).

In addition to these, a science and engineering advisory committee (SEAC), or similar, will be established to advise on different aspects of the SKA Observatory’s science programme, its science and engineering operations, as well as the Observatory’s Development Programme.

6.4.10.3 SKA Users Meetings

The Observatory will organise a regular major SKA meeting that will be open to all stakeholders from across the SKA community. The scope of this meeting will be broad, covering all topics significant to the SKA Observatory, its users and stakeholders. The meeting will be used to:
• showcase SKA science highlights;
• present the activity and progress of the development programme;
• provide workshop and feedback opportunities for discussion of:
  o SKA operations;
  o SRC provision;
  o Key science projects;
  o SKA Observatory Development Programme; and
• provide updates on the future plans and growth of the SKA Observatory.

6.4.10.4 Publications and Dissemination

The SKA Observatory will disseminate news, information, and events that are of relevance and interest to the SKA Observatory, its community, and stakeholders. Additionally, the Observatory will provide support to the user community in communicating their research to a broad audience. This will include, but not be limited to:

• the SKA websites for:
  o press releases and announcements of recent results & other relevant news;
  o animations, simulations, and any other assets illustrating science results;
  o up-to-date information regarding all activities of the SKA Observatory, including but not limited to science, engineering, strategy, outreach, etc.;
  o tailored content for the science and engineering communities, including persistence and access point for documentation, newsletters, and annual reports;

• social media for:
  o engaging broadly with the SKA Observatory’s community and key stakeholders to disseminate results and other content;
  o building and consolidating support and enthusiasm for the SKA Observatory’s activities during construction and operation;
  o disseminating the SKA Observatory’s key messages and values;
  o seizing opportunities and popular trends to maximise the visibility of the SKA Observatory and its mission;

• electronic newsletters providing detailed reports of:
  o progress in the development programme;
  o science highlights from the community including pathfinder and precursor research;
  o summary of activities from the SKA telescopes;
  o relevant information about other activities of the SKA Observatory and its affiliated partners;
  o news of relevance from the SKA Observatory and beyond;
  o events of relevance throughout the world;
  o SKA jobs throughout the SKA partnership;

• annual reports providing details of:
  o reports from the SKA Observatory (DG plus other departments and groups);
  o local news from the offices of the SKA members and observers;
  o report from the SKA Council;
  o reports on the operational performance of the SKA telescopes;
  o reports on the performance and activities of the SKA regional centres;
  o time allocation results and process;
  o scientific research highlights;
o list of SKA research papers and other publications;
o calendar of events;
o list and profiles of employees, new starters, fellows, etc.; and
o report on global outreach impact and human capital development.

In addition, the SKA Observatory will:
o engage with members of the public through regular public talks to disseminate its research;
o conduct educational workshops wherever appropriate; and
o provide teacher resources and lesson plans based on its research to the teacher community.

6.5 Consolidated Operations and Science Groups Resource Tables

The number of staff in the operations and science groups, by function, location and year, is shown in Table 33.

Table 33: Staff numbers by year for the science and operations group.

<table>
<thead>
<tr>
<th>Group</th>
<th>Location</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
<th>2030</th>
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</thead>
<tbody>
<tr>
<td>Science</td>
<td>UK</td>
<td>7</td>
<td>10</td>
<td>10.5</td>
<td>11</td>
<td>14</td>
<td>14</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Operations</td>
<td>Eng. Ops</td>
<td>UK</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AUS</td>
<td>0</td>
<td>7</td>
<td>15</td>
<td>19</td>
<td>28</td>
<td>35</td>
<td>42</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RSA</td>
<td>0</td>
<td>13</td>
<td>19</td>
<td>22</td>
<td>34</td>
<td>41</td>
<td>50</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>4</td>
<td>24</td>
<td>38</td>
<td>45</td>
<td>66</td>
<td>80</td>
<td>96</td>
<td>103</td>
<td>102.5</td>
<td>102.5</td>
</tr>
<tr>
<td>Sci. Ops</td>
<td>UK</td>
<td>13.5</td>
<td>16</td>
<td>15</td>
<td>15</td>
<td>18</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>AUS</td>
<td>0.5</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>13</td>
<td>19</td>
<td>24</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>RSA</td>
<td>0.5</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>13</td>
<td>19</td>
<td>24</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>14.5</td>
<td>26</td>
<td>25</td>
<td>33</td>
<td>44</td>
<td>61</td>
<td>72</td>
<td>75</td>
<td>75</td>
<td>75</td>
</tr>
</tbody>
</table>

6.6 Operations through Construction

The main responsibilities for Operations during the construction phase of the SKA1 are:

- engineering operations supporting the assembly, integration, and verification (AIV) construction activities;
- establishing the support model including personnel training, procuring, and managing spare parts and support equipment;
- maintenance, warranty, and initial support contract management;
- maintenance and support for items not under warranty or covered by an initial support contract;
- engineering and science operations support of commissioning activities; and
- science operations support of science commissioning and leading the science verification phase.

This section presents the ramp-up of operational staff during the construction phase in order to support these three activities.

All preceding chapters of this document have only considered the routine operations phase, i.e., when SKA1 is fully deployed, commissioned, and verified. The scope of this plan, however, includes all
phases from construction through to decommissioning. A high-level summary of the project lifecycle is depicted in Figure 34.

![Figure 34. The schematic lifecycle of the SKA Observatory (not to scale). The green colour represents the activity of operations, ramping up during the construction phase, then in the lead role throughout the anticipated 50-year lifespan of the Observatory, and then ramping down again during decommissioning of the SKA telescopes.](image)

6.6.1 Operations during the Construction Phase

The construction phase of the project will commence at T0 (Figure 34), defined as the point in time at which the SKA1 Construction Proposal and a companion SKA Observatory Establishment and Delivery Plan have both been approved by the SKA Observatory Council. Importantly, this milestone releases funding that allows procurement for construction activities to commence.

The construction of the SKA telescopes, including the SKAO resources required through the observatory budget, is described in the SKA1 Construction Proposal. As both SKA1-LOW and SKA1-MID will be continuously integrated and verified there is necessarily an overlap in time of construction and operations activities. As soon as the first component is accepted by the Observatory, it will need to be supported and maintained by Observatory operations. A system to accept ownership and responsibility for the support and maintenance of hardware, firmware, and software will be established. During construction, operations will be responsible for maintenance while items that are under warranty or initial support contracts will be maintained by a contractor. Operations will be responsible for the management of those contracts where the in-house capacity for maintenance has not yet been established.

From the perspective of telescope operations, the activities arising during this phase of the project will be:

- implementation of the EMS (§6.4.6.11);
- population of the EMS with supplier-provided and internally generated documentation;
- training of maintenance and support personnel;
- preventive and corrective maintenance of products accepted by AIV;
- the management of warranties and initial support contracts where the internal capacity for that work does not exist;
- support for, and participation in, the commissioning and verification aspects of the construction project as specified in the SKA1 science commissioning and verification plan [RD20];
• working with the SRC steering committee to implement an ensemble of SRCS, and to support the regions in their implementation of individual SRCS;
• implementing the operational interfaces to the SRCS; and
• establishing an operational presence in the host countries and commissioning the operational facilities (i.e., SOCs, SPCs, and EOCs).

There will be integrated teams to run and manage the commissioning of the SKA1-LOW and SKA1-MID telescopes, each located in the respective host country. These teams will be comprised of [RD20]:

• engineering (hardware and software);
• verification coordination;
• science commissioning;
• operations; and
• quality assurance.

6.6.1.1 Operations during AIV

The SKA1 Roll-out plans ([RD25] for SKA1-LOW and [RD26] for SKA1-MID) describe the sequential assembly, integration and verification of new hardware, firmware, and software. These roll-out plans define six distinct phases:

1. prototype system integration (PSI) and integration test facilities (ITF);
2. array assembly 0.5;
3. array assembly 1;
4. array assembly 2;
5. array assembly 3; and
6. array assembly 4.

The PSI and ITF tests as much of the system as possible within a laboratory environment. It is not anticipated that there will be a great demand on operations staff during this initial phase. Table 34 shows how with each array assembly milestone, approximately 1 year apart, the telescope array grows, as characterised by the number of stations (SKA1-LOW) and dishes (SKA1-MID). The observing modes delivered with each array assembly is noted. It is clear that the rate of growth of the array and the functionality delivered is quite significant from AA1 onwards.
Table 34: Characteristics of each Array Assembly (AA) milestone and the functionality delivered.

<table>
<thead>
<tr>
<th>Telescope</th>
<th>AA0.5</th>
<th>AA1</th>
<th>AA2</th>
<th>AA3</th>
<th>AA4</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW</td>
<td>Stations</td>
<td>8</td>
<td>18</td>
<td>64</td>
<td>256</td>
</tr>
<tr>
<td></td>
<td>Observing Modes*</td>
<td>Basic Imaging</td>
<td>Pulsar Timing, Dynamic Spectrum</td>
<td>Pulsar Search, Transient Capture</td>
<td>VLBI</td>
</tr>
<tr>
<td>MID</td>
<td>Dishes</td>
<td>4</td>
<td>8</td>
<td>64</td>
<td>121</td>
</tr>
<tr>
<td></td>
<td>Integrated MeerKAT Dishes</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Receiver Bands</td>
<td>1, 2</td>
<td>1, 2</td>
<td>1, 2 5 (on 32 Dishes)</td>
<td>1, 2 5 (on 64 Dishes)</td>
</tr>
<tr>
<td></td>
<td>Observing Modes*</td>
<td>Basic Imaging</td>
<td>Basic Pulsar Timing</td>
<td>Pulsar Search</td>
<td>Scaled up Capability of Existing Functions</td>
</tr>
</tbody>
</table>

* The observing modes shown are in addition to those delivered in previous array assemblies.

6.6.1.1.1 Operations Roles and Responsibilities

The lead and support responsibilities of the AIV, commissioning, engineering, and science operations teams are summarised in Table 35. Once the products that support those functions are accepted for commissioning, they need to be maintained by the operations teams. The maintenance teams must familiarise themselves with the equipment and their maintenance requirements. The staff levels required during this time (§6.6.3.1) is estimated via a simple scaling of the characteristic size of the array at each array assembly against the level of support required for routine operations (§6.4.6.8 and §6.4.6.9).

As well as the clear role for maintaining and supporting the integrated and verified components of the telescopes, the operations groups at each telescope will play a supporting role to AIV activities as required, including the provision of Telescope Operators.

There will be an iterative process as products (dishes, stations, etc) are integrated and verified by AIV. Specific roles for operations staff include:

- establish a support system, including training, spare parts, and manuals;
- support acceptance of products and check operations manuals and documentation delivered with products;
- support integration of products including installation and safety procedures;
- operate and maintain equipment as required;
- management of warranties and of any service level and support agreements that may be applicable; and
- maintain and respond to failure reports.
Table 35: Team lead and support roles during commissioning and science verification activities.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Leads</th>
<th>Supports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration &amp; Verification</td>
<td>AIV</td>
<td>Commissioning, Engineering and Science Operations</td>
</tr>
<tr>
<td>Commissioning</td>
<td>Commissioning</td>
<td>AIV, Engineering and Science Operations</td>
</tr>
<tr>
<td>Science Verification</td>
<td>Science Operations</td>
<td>AIV, Commissioning, Engineering Operations</td>
</tr>
</tbody>
</table>

6.6.1.2 Observing Mode Rollout

The Rollout plans for SKA1-LOW [RD25] and SKA1-MID [RD26] (see Table 34) describe the observing modes that will be enabled by the hardware and software delivered by AIV at each of the array assemblies. While the functionality rollout is necessarily closely linked to the commissioning requirements, the prioritisation of observing mode availability is made at the science commissioning stage, as described in the SKA1 science commissioning and verification plan [RD20]. At this stage, the prioritisation will be driven by mode complexity, allowing for a commissioning schedule that sensibly builds up to the full functionality of each telescope.

As described in [RD20], once individual modes have been commissioned they will be offered for science verification, allowing for a demonstration of the performance and verification of the modes against the L0 science requirements [AD6]. Approximately 6 months before the end of AA4 we will conduct a cycle 0 capabilities review to determine what modes will be available for the first call for proposals. A more formal operations readiness review will follow AA4 and will include an observing mode assessment.

6.6.1.3 Science Commissioning and Science Verification

The aim of commissioning and science verification is to deliver observing modes to operations at the operations readiness review. Specifically, (science) commissioning will focus on delivering a working end-to-end system that can be used to perform system verification, including the execution and analysis of astronomical observations with the aim of debugging the system.

The purpose of science verification is to demonstrate the scientific performance of SKA and hence verify against level 0 (Science) requirements [AD6]. Science verification provides end-to-end test and demonstration of the entire SKA for specific observing modes. The definition of each ‘end’ will clearly evolve (e.g., proposal submission will not be verified and tested in an end-to-end system until AA4).

Although the skills required to carry out science commissioning and science verification overlap, the roles and intent of the two are distinct. Where science commissioning is focussed on delivering functioning observing modes, science verification aims to characterise the telescope performance. It is a rehearsal for science operations and will also serve to commission the science operations of SKA. As such, this activity is led by science operations, supported by the commissioning and AIV teams as necessary.

6.6.1.3.1 Operations Roles and Responsibilities

In addition to the responsibility of the operations teams to maintain and operate the integrated and verified components of each telescope, this phase brings additional responsibilities for the operations group, especially for science operations (Table 35).

Science operations teams will work closely with the commissioning scientists (accounted for in the construction support budget).
Importantly, science verification provides an opportunity for community involvement during the construction phase of the project. Announcements to the community will be made inviting suggestions for short observing projects to utilise and test specific observing modes and capabilities of the SKA. These announcements will not be general, open, calls for proposals. Priority will be assigned to projects that test and stress the objectives for each science verification campaign. Finally, data releases from the science verification campaigns will be public and access will be made available via the SRCs.

Specifically:
- support through engineering, operator and science support;
- maintain failure reporting;
- witness verification events;
- schedule and execute commissioning observations as required;
- schedule and execute science verification programme;
- communication with community for science verification events; and
- interface with SRCs for delivery of science verification data to users.

6.6.2 Transition to Operations

The final activity of the construction project will be to demonstrate the ability of the Observatory to execute a selected set of day-one observing modes, from proposal preparation through to data delivery. The construction phase of the project will conclude with an operations readiness review, marking the formal handover from construction to operations. This review will evaluate the verification evidence in order to determine whether the telescope system and all its support hardware, software, personnel, procedures, and user documentation accurately reflect the deployed state of the telescope. A successful operations readiness review will be used to formally declare the telescope as operational.

The conclusion of the construction project is an important management milestone, but it does not mark the end of construction-related activities. For instance, software development will continue on an essentially continuous basis. Nevertheless, the operations readiness review is a critical milestone because it marks the point at which the Observatory will be ready for science programmes to commence. As is normal with new, large and complex projects, it is anticipated that the first two years of the operations phase will be dominated by debugging and commissioning activities; following this, operations should become more routine.

6.6.3 Operations Staffing during the Construction Phase

The staffing profile for the 10-year operations plan presented in §7.1 is presented in Figure 35. This shows the ramp-up of operations staffing during the construction phase of the project specifically to support those construction activities (see above) and to prepare for operations readiness and the start of the operational phase of the SKA Observatory’s lifecycle (Figure 34).

Operations staffing starts off at a relatively low-level but then steadily begins to increase over time, reflecting the increasing amount of work needed as the arrays build-up and the commissioning and verification activities ramp-up. This slow, almost monotonic, rise in operations staffing is in line with the gradual and steady roll-out of the SKA telescopes [RD25][RD26]. By the end of construction, the staff accounted for by the Observatory operations budget represents about 75% of all SKA staff.
Note that the BE staffing that supports the construction and operations activities stays relatively steady throughout the 10-years of this operations plan.

The construction support numbers presented here do not reflect the total staffing that is needed to construct the SKA telescopes. Contracts will be issued to procure, manufacture, assemble and deliver the different components, systems and sub-systems that make up the complete operational telescopes. The staffing for these is presented and justified in the Construction Proposal and paid for by the capital cost for construction budget. Here, construction support reflects the staffing required to support and manage those all construction activities (e.g., project management, verification, and commissioning). Staffing in this area starts high and grows slowly until mid-way through the construction phase where the staff numbers plateau.

The end of the construction phase also marks the end of the construction support budget line (there is no construction to support!) and the number of staff accounted for by that budget falls to zero. Those roles that were involved in construction activities either cease to exist at that time or move over to operational roles (e.g., the majority of the computing and software roles). This accounts for the significant upturn in operations staffing at the end of construction.
Figure 35. Staffing profile for the 10-year period between 2021 and 2030 for the SKA Observatory. The total staff numbers are shown by the grey area, with the staffing levels in Observatory operations (red), construction support (purple), and business enabling (blue) shown by the lines. The assumed transition between the end of construction and the start of routine operations is shown to occur in 2028.

Figure 36. The profile of operations staff distributed across the three sites of the Observatory, the GHQ (purple), the SKA1-LOW (red) telescope, and the SKA1-MID (blue) telescope. The total operations staffing is shown by the grey area.
Figure 37. Engineering operations (top) and science operations (bottom) staffing profiles at the three sites of the Observatory - the GHQ (purple), SKA-LOW (red), and SKA-MID (blue). Note that for the bottom panel, the SKA-LOW and MID science operations staffing is equal and so the red line for LOW is not seen. The total number of engineering and science operations staff is shown by the grey area.
6.6.3.1 Engineering and Science Operations

Figure 36 shows the profile of operations staffing across the three sites of the Observatory. The growth in numbers through the construction phase is steady, rising faster at the telescope sites. By the time of routine operations, the staffing on the three sites is more or less equal.

Figure 37 shows the staffing in engineering (top) and science (bottom) operations across the three sites. Demand on engineering operations is not high at the start of the construction phase but then once the array begins to significantly grow in size, and more elements and components need to be operated and maintained, the staff numbers grow accordingly. There are more engineering operations staff for SKA1-MID than for SKA1-LOW purely because the dishes of MID have more components and sub-systems than LOW stations. Otherwise, the support levels are more or less the same (see §6.4.6.8 and §6.4.6.9).

6.7 Operations delivery risks

A number of high-level cost uncertainties and risks to the delivery of Observatory operations have been identified and will continue to be tracked in the Observatory risk register maintained by the assurance function, and actively managed. We first identify cost uncertainties that should be retired, or significantly reduced, by the time the Observatory is established.

6.7.1 Cost Uncertainties

6.7.1.1 On-Costs and Indirect Costs for CSIRO and SARAO Employees

An estimate of staffing on-costs and indirect costs has been included in the plan, representing costs of employing staff via CSIRO and SARAO. Salary on-costs such as superannuation contributions and other statutory payroll cost commitments have been estimated as 30% of salary, and indirect costs associated with the recharge of employees such as payroll administration has been estimated as 15% of salary.
Whilst discussions have commenced with CSIRO and SARAO, the exact methodology of calculation of total staff costs has not been finalised. As an example of the cost sensitivity, if the actual rate of on-costs and indirect costs is 55%, it would amount to an additional €8.9 M over the ten years of the Plan with an associated underestimate in 2030 of €1.2 M. Over the full 10 years, this would result in an increase in total staff costs of 2.5%, and 3.2% in steady-state operations.

6.7.1.2 Building Costs

The telescope host countries are responsible for making available the engineering operations centres, science operations centres and science processing centres. SKA is responsible for paying rent and operating costs for these buildings. The costs for these facilities are not yet fully determined at the time of writing.

Responsibility for fitting out the interiors of the buildings provided by the telescope host countries has not yet been agreed. If this is not done by the host countries (implying that costs are folded into the rent) then these will be one-off costs to SKA. We estimate these to be no more than €1 M. If these costs are still not determined at the time of approval of this plan, we anticipate dealing with this from the DG’s contingency.

6.7.1.3 Unidentified Costs

It is possible that costs that cannot be avoided have been overlooked, most likely in those areas of responsibility close to the interfaces between SKA and the operations partners, CSIRO and SARAO. A great deal of work is being done through a tri-lateral SKA Operations Forum to work through details of the Operations Plan, including implementation plans and scenarios, with CSIRO and SARAO staff with direct experience of telescope operations on the SKA sites, to build a comprehensive understanding of the implementation of this Plan. We anticipate dealing with any remaining missing costs, which we are confident are small and unlikely to exceed €0.5 M per telescope per year, from the DG’s Contingency.

6.7.2 Specific Risks

6.7.2.1 Dependence on SRC Network and Provision of the SKA Science Archive

The delivery of SKA science is dependent on the SRC network. SKA leadership and staff are very closely engaged in SRC planning and will continue to be directly involved in planning and in the delivery of SRC functions. The SRC steering Committee reports to the SKA DG, and its membership includes SKA science operations staff. At SKA Board meeting 32 in May 2020 the Board noted that the SRC network is critical to the delivery of SKA science but did not approve the proposed governance model. SKA members have indicated strong support for resourcing ongoing work related to the design of the SRC network, and the need to resource SRC network capabilities to support the delivery of SKA science.

Arguably the most significant element of risk associated with the dependence on the SRC network relates to the provision of the science data archive by the SRCs. The key mitigation of this risk is the very close engagement, at government, funding agency, and Observatory level across the member countries, and the close involvement of SKAO staff in the SRC steering committee.

In the event that SKA needs to host the science data archive within the Observatory, the additional cost is estimated to be €15 M p.a.
There is a range of other risks to SKA Observatory operations, and more specifically to the effective delivery of SKA science impact, associated with the partnership between the SKA Observatory and the SRC network. Of these, the most significant are as follows:

- the sum of SRC network resources may not match Observatory and user plans and expectations;
- a lack of integration of the user interfaces to Observatory and SRC network functions could lead to a disconnected and inefficient user experience;
- users’ ability to analyse SKA data may be compromised if the SRC network support for post-processing software is insufficient; and
- excessive Observatory resources may be required to coordinate Observatory – SRC interfaces and SRC resources and activities because of limited authority and control.

SRC governance is a key focus of the SKA Board (and the Council preparatory task force) at the time of writing this Plan. The most effective mitigations for these risks are a combination of the following:

- continued engagement of SKA Observatory staff in the SRC steering committee;
- empowering the SRCSC working groups to advance the detailed planning and design of the SRC network, with extensive input from SKA Observatory staff and a range of other experts from the member countries;
- identification of a clear and relatively simple governance structure, with agreed roles and responsibilities; and
- the addition of an SRC architect role in the SKA Observatory staffing plan to drive the design of the SRC network.

Finally, we note that while provision has been made for the cost of data links for the transfer of scientific data from the telescope host countries to the most cost-effective point in the northern hemisphere, the costs associated with further distribution to or within the SRC network, or for redundant data links, have not been included in this plan.

6.7.2.2 Exchange Rate Exposure

Financial impacts from movements in currency is a major known risk for the Observatory. During the operations phase, it is expected that expenditures will be mostly incurred in Australian Dollars, South African Rand, and British Pounds whilst the funding to the Observatory will be budgeted in Euro. The intention is to implement financial guidelines that will see the Observatory receive the host country (UK, RSA, and AUS) contributions denominated in their local currency. Collecting nearly 50% of our funding in these currencies provides a natural hedge during each funding year, as we will receive amounts in AUD, GBP, and ZAR that can be held in accounts for settling expense payments in those currencies.

Whilst funding contributions are yet to be finalised the two telescope host countries are each committed to a level of around 14% with the HQ host country committing a 15% share. These commitments are for both construction and operations. In full operations, the costs incurred are dispersed almost equally across the three host countries, and therefore, across the corresponding currencies.

The funding model of host countries paying in their respective currencies therefore reduces the exchange rate exposure by about 50%.

Responsibility for management of all treasury functions, including foreign exchange, will rest with the HQ finance team. The staff plan has identified the need for treasury expertise to develop and
implement the Observatory wide currency strategy. We envisage extensive use of foreign currency accounts, forward contracts and options to actively manage our exposure and minimise downside risk where it is cost-effective to do so.

6.7.2.3 Power Costs

The cost of power to operate the telescopes and associated computing centres has been estimated using the current baseline cost of grid power where available\(^\text{23}\), and diesel generators to supply the remote Australian SKA1-LOW site, and then assuming that a saving of 20% of that total can be realised through long-term power purchase agreements, which is approximately half the saving that initial requests for information already conducted in South Africa and Australia indicate may be achievable. More detail is provided in section 8.4.1. There is a risk that this projected saving may not be realised. If the actual cost of power were to match the grid/diesel baseline estimate, the additional cost over the 10-year period covered by this plan would be €19.6 M, and the ongoing additional cost from 2028 would be €3.7 M p.a.

A different risk relates to the future escalation of grid power costs. Grid power costs in Western Australia, relevant for the SKA1-LOW SPC but not for the telescope itself, continue to be relatively stable. However, the cost of grid power in South Africa has risen rapidly, by a factor of four over the past decade. This is relevant for both the operation of the SKA1-MID telescope and the SPC in Cape Town. The budget allocation for power in South Africa in this plan is approximately €3.5 M in steady-state. The primary mitigation of this risk is to pursue a power purchase strategy that seeks a long-term power purchase agreement with a high renewables penetration that reduces the dependence on grid power supplied by ESKOM. This strategy is being pursued aggressively.

6.7.2.4 Delayed Delivery of EOC, SOC, SPC or BAF

There is a short-term risk to SKA operations related to the dependence on the telescope host countries to deliver the necessary operations buildings at the time needed. This is mitigated through close working engagement between SKA staff and the telescope host country entity teams. The event that this risk is realised, SKA would seek to identify suitable temporary accommodation. This may come at additional cost, but we would expect the relevant host country entity to bear essentially all such costs. We anticipate a maximum impact of €1 M on SKA and would deal with this if it arises through the DG’s contingency.

6.7.2.5 In-Country Collaborator Priorities or Practices Conflict with SKAO

The collaboration model for operations adds complexity and risk. At the highest level, there is a risk that the priorities or practices of one or both collaboration partners may conflict with the needs of SKAO. A key issue in this respect is that the partner organisations will be the employers of the majority of staff working to deliver SKA operations in the telescope host countries.

To mitigate this risk, high-level collaboration MOUs have been drafted and will be signed around the time of approval of this plan. Those MOUs will be evolved into more detailed legally binding agreements. The fact that the collaborating partners have the role of delivering on the commitments of the respective Australian and South African Governments, i.e., the telescope host country members of the Observatory, is itself an effective mitigation of this risk.

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\(^{23}\) A small number of remote SKA1-MID antennas are assumed to be powered by stand-alone PV generators
6.7.2.6 Limitations of 4.5/2.5 FIFO Model for SKA1-LOW

The physical remoteness of the SKA1-LOW site in Australia poses a unique risk. In particular, it drives the fly-in fly-out (FIFO) mode of operations adopted in this plan. We believe the risk of the 4.5 days on, 2.5 days off mode of staff presence at the site is manageable and has been demonstrated as effective through CSIRO’s operation of the ASKAP telescope over a number of years. However, SKA1-LOW is a substantially larger undertaking and quite different technology and direct experience is likely to reveal some different challenges in its operation.

The partnership with CSIRO is the most effective mitigation of this risk. If necessary, the engineering operations staffing model may need to evolve as experience is gained with SKA1-LOW operations, but we believe the likelihood of this is low. If this is required, the aim would be to redistribute staff presence at the site over the week while not materially increasing the overall complement of engineering operations staff.

6.7.2.7 Safety and Access of Remote Sites – especially distant spiral arm elements

Remote work always involves an element of risk, and the geographical span of the SKA1 telescopes in sparsely populated areas is an important consideration. However, there is substantial experience of direct relevance within CSIRO and SARAO, and the operations plan and implementation model, including standard operating procedures, working modes, and safety plan are all being built from the ground up using that knowledge and experience.

We believe that with these mitigations in place, the residual risk is low.

6.7.2.8 Fair Work Return Expectations

Members have a strong requirement for fair work return from contributions to funding of the construction of SKA1. Some members have also indicated a desire for similar outcomes in operations. However, by its very nature, the majority of activity and therefore expenditure during operations occur within the host countries, limiting opportunities for expenditure to be distributed according to a priori determined spread. There is a risk that expectations or requirements imposed by one or more of the non-host country members could impose substantial additional complexity and or cost on the Observatory.

To mitigate this risk SKAO continues to work closely with members to understand expectations and shape those expectations through transparent planning. SKAO has also undertaken an exercise to identify a range of activities relevant in the operations phase of the Observatory that are likely to provide opportunities for the industry in non-host countries. These opportunities will be discussed with members through the CPTF and/or Council.

6.7.2.9 AUS/RSA Work Permits for IGO Spouses

The nature of the SKA Observatory as an intergovernmental organisation (IGO) means that staff employed by SKA Observatory will be subject to certain privileges and immunities. In particular, staff members who are not nationals of the country in which their role is based will not be subject to the usual visa requirements to enter and work within that country. The UK Government has determined that similar provisions will apply to spouses and other immediate family members regarding entry and permission to work in the UK.

At the time of writing the Observatory has not been informed of the positions of the Australian and South African Governments. In the event that spouses and families of prospective IGO employees face
difficulties in meeting requirements to enter and work in Australia and/or South Africa, the ability of SKA to operate will be compromised, or extra cost will be incurred.

This risk is currently rated as moderate. This plan envisages approximately 10 IGO employees in each telescope host country, some filling roles that require skills in short supply on the global labour market. If it proves necessary to provide additional benefits, for example, to compensate for spouses not having permission to work, this could have the effect of doubling the cost of employment of each IGO staff member in Australia and South Africa. While substantial at an individual level, this would add just 5% to the steady-state cost of operations.

### 6.8 Observatory Operations Costs

Observatory operations staff costs comprise those associated with paying SKAO employees and payments to CSIRO and to SARAO for the costs associated with paying employees of those organisations working under SKAO direction on the delivery of SKA activities in the telescope host countries. The staff and non-staff costs associated with Observatory operations are shown in Table 36 and Table 37.

Table 36: Staff Observatory operations costs by year and employer.

<table>
<thead>
<tr>
<th>Employer</th>
<th>Amount (€M)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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<tr>
<td></td>
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<td>2022</td>
<td>2023</td>
<td>2024</td>
<td>2025</td>
<td>2026</td>
<td>2027</td>
<td>2028</td>
<td>2029</td>
</tr>
<tr>
<td>SKAO staff</td>
<td>6.2</td>
<td>3.8</td>
<td>3.8</td>
<td>4.3</td>
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<td>5.9</td>
<td>7.1</td>
<td>10.9</td>
<td>14.5</td>
</tr>
<tr>
<td>CSIRO staff</td>
<td>0.06</td>
<td>1.1</td>
<td>1.8</td>
<td>2.3</td>
<td>3.3</td>
<td>4.2</td>
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<td>SARAO staff</td>
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<td>2.5</td>
<td>4.1</td>
<td>5.4</td>
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<tr>
<td>Total</td>
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<td>5.7</td>
<td>6.7</td>
<td>7.8</td>
<td>10.2</td>
<td>12.3</td>
<td>14.4</td>
<td>22.5</td>
<td>29.8</td>
</tr>
</tbody>
</table>

Table 37: Non-staff Observatory Operations costs by year and country.

<table>
<thead>
<tr>
<th>Country</th>
<th>Amount (€M)</th>
<th></th>
<th></th>
<th></th>
<th></th>
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<tr>
<td></td>
<td>2021</td>
<td>2022</td>
<td>2023</td>
<td>2024</td>
<td>2025</td>
<td>2026</td>
<td>2027</td>
<td>2028</td>
<td>2029</td>
<td>2030</td>
</tr>
<tr>
<td>UK(^{24})</td>
<td>0.3</td>
<td>0.1</td>
<td>3.8</td>
<td>3.9</td>
<td>3.9</td>
<td>3.9</td>
<td>4.1</td>
<td>4.6</td>
<td>6.6</td>
<td>6.5</td>
</tr>
<tr>
<td>Australia</td>
<td>0.1</td>
<td>1.8</td>
<td>4.7</td>
<td>8.2</td>
<td>11.3</td>
<td>17.1</td>
<td>19</td>
<td>20.6</td>
<td>20.5</td>
<td>20.9</td>
</tr>
<tr>
<td>South Africa</td>
<td>0.06</td>
<td>1.5</td>
<td>5</td>
<td>7.9</td>
<td>11.9</td>
<td>17.1</td>
<td>18.9</td>
<td>21.7</td>
<td>20.9</td>
<td>20.1</td>
</tr>
<tr>
<td>Total</td>
<td>0.45</td>
<td>3.4</td>
<td>13.5</td>
<td>20</td>
<td>27.1</td>
<td>38.1</td>
<td>42</td>
<td>46.9</td>
<td>48</td>
<td>47.5</td>
</tr>
</tbody>
</table>

\(^{24}\) Includes €3.75 M per year from 2023 for computing hardware refresh, and €2 M per year from 2029 for decommissioning.
7 SKA Observatory Development Programme

7.1 Overview

It is universally recognised that a well-funded and carefully targeted development programme is essential to maintain the scientific competitiveness of any observatory. The purpose of the SKA Observatory Development Programme (SODP) is to enhance the scientific productivity of the Observatory by:

- adapting to changes in the scientific landscape and priorities;
- enabling new science;
- restoring descoped functionality;
- improving output and reliability; and
- reducing operational cost.

The SODP is divided into projects, which deliver major improvements, and studies, which are intended to evaluate new ideas and bring them to an adequate technology and manufacturing readiness level (TRL/MRL) to become potential projects. The process requires prioritisation of research and development in the context of science and technology roadmaps.

The present discussion is restricted to SKA1 and concentrates on the initiation of the SODP and its evolution as the Observatory transitions from the construction phase into the operational phase.

7.2 History

The idea of an upgrade programme for the SKA was first introduced in the Medium Range Implementation Plan (2013) which proposed a budget of €5 M in Year 6 of construction, with €20 M thereafter. The term “SKA Observatory Development Programme” was introduced in 2015 (SKA-BD-19-11) and the concept was refined in 2016 (SKA-BD-22-19). At that time, it was proposed that the existing Advanced Instrumentation Programme (AIP) should transition into the SODP during the course of construction. The most recent iteration, concerned primarily with the evolution of the AIP, was presented to the SKA Board in 2019 (SKA-BD-29-09). At that point, a revised funding profile was also proposed.

The present outline plan represents an evolution of these earlier ideas, with additional detail. It has been influenced by development programmes at other leading observatories, particularly ALMA which, as a large-scale, multinational synthesis array, presents similar opportunities and challenges. The technical areas covered by the SKA AIP (advanced single-pixel feed receivers; phased array feeds and mid-frequency aperture arrays) will form part of the SODP in the future and remain important for Observatory development on a range of timescales from near-term upgrades of SKA1 to long-term thinking about SKA2.

7.3 Funding Assumptions

The funding available for the SODP in the 10 years from T0 is expected to be €40 M (2020 euros), with the presupposition of a slow ramp-up during construction, the ongoing budget after that is expected to be €20 M per year. A plan for the ramp-up of funding and activity during the first decade of the Observatory is given below.
7.4 Principles

The guiding principles of the SODP (slightly modified from SKA-BD-19-11) are as follows:

1. SODP projects should aim to offer potentially significant enhancements to the scientific capability of the SKA Observatory.
2. SODP projects should provide a clear path to deployment on or for the SKA. The SKAO is not resourced to fund blue-sky research and development.
3. SODP projects will generally be expected to be undertaken by teams led by an organisation from one of the SKAO member (or associate member) countries. Large projects would be expected to involve international collaborations. Some (usually smaller) projects may be carried out in-house by SKAO staff.
4. SKAO funding of institutes participating in SODP projects will generally be limited to organisations from SKAO member (or associate member) countries. Organisations from other countries may participate but would generally be expected to do so via their own resources.
5. When appropriate, industry should be integral to an SODP project proposal team. Without industry participation, many SODP projects would risk not having access to the necessary expertise to adequately address key areas, e.g., integration, modular design, design for manufacture, or cost.

7.5 Key Technologies

A (non-exhaustive) list of already-identifiable key technology areas or capabilities which could provide significant enhancements in scientific output for SKA1 is given below.

- Improved frequency coverage
  - Additional receiver bands (Bands 3, 4, 5c)
  - Increased instantaneous RF bandwidth (wide-band feeds)
- Higher sensitivity
  - More dishes/stations
  - Lower noise
- Digitisation and correlator
  - Integrated front ends
  - Improved photonics
  - More instantaneous bandwidth
  - More channels
  - More bits
  - Improved resilience to RFI
- Spatial multiplexing
  - Phased-array feeds (dishes)
  - More station beams (aperture arrays)
  - More tied-array beams
- Higher spatial resolution (longer baselines)
- Upgraded computer hardware and software
  - Algorithms (e.g., RFI rejection and flagging, direction-dependent calibration)
  - Storage
  - Networks
  - Data processing hardware (in addition to regular refresh)
  - Improved cooling or reduced power consumption
  - Major OMC or SDHP upgrades
• Scheduling and response to external events
  – Faster response to triggers
  – Better transient buffering or localisation
• Better access to data
  – Archive accessibility
• Environmental monitoring
  – Ionospheric sensing
  – Geomagnetic field models
  – Predictive models of observing conditions

In addition, improvements in reliability and operational cost of the Observatory could contribute directly to the amount of science delivered for a given cost and time. Examples include economies in power generation; improved remote diagnostics; better network reliability; more effective alarm systems and predictive maintenance.

Selecting the best compromise between scientific/operational effectiveness and cost requires careful planning, as described in the next section.

7.6 Road Maps and the SKA Development Plan

The development plan for SKA will be created and periodically updated in close collaboration with the community of users and developers. There are three elements to the process: a science road map; a technology road map; and the development plan itself, which describes a feasible, prioritised, and costed programme synthesised from the two road maps. These three elements are described in more detail below.

Given the long lead times required for major upgrades to telescope systems of the scale of SKA, and the intention to start a study programme, development of the two road maps should start early in the construction phase (year 1). A preliminary development plan should be in place in year 2 to guide the assessment of studies. By the time of the first calls for major development projects (year 8), an approved development plan will be essential.

7.6.1 Science Road Map

The science road map is intended to identify emerging research areas (particularly synergies with other facilities) which should drive changes in priorities for SKA development. Obvious recent examples include multi-messenger astronomy (gravitational waves, neutrinos, cosmic rays); new observatories operating across the electromagnetic spectrum; very large-scale surveys; and transient detection (e.g., fast radio bursts). Changes of interest within the astronomy community, often prompted by new types of observation or theory, should inform priorities for the SKA, including the SODP.

The science road map will be updated periodically by an advisory group led by the SKA Science Director, with extensive community involvement, and supported by the SKAO science team. Community input should also be solicited by periodic workshops, perhaps held in association with SKA science conferences.
7.6.2 Technology Road Map

In parallel, the technology road map will describe technical developments relevant to the SKA, from proof of concept to mature technologies or techniques ready for deployment on the arrays. The remit is necessarily broad, covering everything from infrastructure (e.g., power generation) to advanced instrumentation and high-performance computing. The TRL and MRL of potential upgrades and the likely costs will be of particular relevance.

The technology road map will also be updated at intervals. The responsible group will be led by the project engineer, again drawing on the wider community and with the support of SKAO staff. Periodic technology-related workshops for the wider community are anticipated.

7.6.3 SKA Development Plan

The development plan will represent a synthesis of the science and technology road maps. It will balance short and long-term upgrade priorities in different areas to maximise scientific output within the allocated budget. This will require careful tensioning of new ideas against the restoration of previously planned capability and must also take into account the geographical distribution of participating groups and collaborations. The group responsible for the development plan will be chaired by the System Scientist and will include representatives from both road map groups. The plan will be presented to the SEAC (or its successor) for approval and will be circulated within the wider SKA community.

Figure 38. Representation of the flow from road maps to development plan to new capabilities.
7.7 Development Studies

Recognising that development projects for the SKA telescopes are potentially complex and expensive, with long lead times, there is a clear need for careful preparation and evaluation. Development studies are small-scale activities, primarily designed to prepare for larger development projects, but occasionally delivering functionality in their own right.

Not all studies will necessarily lead to projects: the intention is to feed into the development plan by providing a range of costed options with well-understood capabilities. Examples of eligible studies include:

- science cases for upgrades (perhaps including support of meetings to solicit input from the community);
- feasibility and design studies;
- improvement of TRL and/or MRL;
- costing investigations; and
- proposals for improvements in operational efficiency.

The output of a study should ideally be a costed project proposal, at least at the preliminary design review level, or a defined step towards such a proposal. Studies are not intended to support basic research and development, which is outside the scope of SKAO funding. A minority of studies will produce equipment (or, more likely, software) which is usable immediately by the Observatory without further development, for example, a small-scale data analysis application. It is unlikely that studies relevant only to SKA2 will be funded in the early years of the programme.

Studies will be solicited on a 2 or 3-year cycle and calls will be open. Co-funding from national or trans-national agencies will be encouraged but will not be mandatory. There will need to be a fairly long interval between the initial call and the deadline for receipt of proposals to allow for alignment with external funding cycles. The upper limit for funding of an individual study is likely to be around €300 k, with €50 k - €100 k more typical.

Study contracts will be firm, fixed price with clear deliverables (documentation and optionally hardware and software). Review of study proposals will be conducted by SKAO, with appropriate external input.

7.8 Development Projects

In contrast to studies, development projects are expected to deliver major increments in capability and scientific productivity. They will have durations from 1-5 years and budgets of up to €20 M, although small-scale projects will also be supported. Project proposals will normally be submitted in response to a directed call, based on the development plan. In some cases, enhancements will be interdependent (e.g., a new feed might require additional correlator and SDHP resources), and coherent planning will be essential to achieve the scientific potential. For that reason, unsolicited projects are unlikely to form a large part of the programme (but can be submitted and will be judged in competition). Final selection of projects will be based closely on the development plan and will balance new science, efficiency improvement, restoration of descoped capability, and new opportunities, as well as small and large-scale initiatives.

Proposals must include a science case, together with project management, systems engineering, test and QA plans and costings. It is expected that the majority of large projects will be linked to the output of earlier studies (which will have established the science case, design feasibility, and TRL/MRL as
appropriate) but this is not essential. Large, long-term projects would be expected to be at preliminary

design review level before acceptance.

Co-funding of projects from national or trans-national sources will be strongly encouraged, but not

mandatory.

Proposals for substantial projects will be subject to a high-level of scrutiny. Scientific, technical, and

programmatic assessments of proposals will be made by SKAO, involving external reviewers as

appropriate. Cost and resource estimates for the work proposed will be independently assessed, as

will project timelines, management processes and access to suitably skilled resources, and evidence

of ability to deliver the proposed outcomes. Such proposals will also be required to address the likely

impacts on operations and the SKA Observatory systems, and downstream implications for the

delivery of science outcomes.

All projects will be assessed by the Observatory to establish whole-of-life costs including operations

implications, resource requirements, and other long-term impacts. Such factors will be a significant

consideration in decisions regarding the funding of projects through the SODP.

It is expected that the SODP will provide opportunities for engagement across the entire SKA

partnership and that much of the funding will flow back to industry and institutes within member

countries.

7.9 Eligibility and Selection

Detailed criteria regarding eligibility, assessment, and approval processes will be developed by SKAO

and approved by the Council. Such information will be publicly available.

7.10 Resourcing and Managing the Development Programme

Staffing for support of the SODP within the Observatory is already accounted for elsewhere. The

Science Director, Project Engineer, and System Scientist play key roles as noted earlier. Scientific,

Domain Specialist, and project management effort will be provided at appropriate levels from within

the science and programme directorates, with the involvement of operations staff as needed. Studies

will be managed using a light-touch process. Depending on the duration and cost of the study, kick-

off, final review, and (optionally) mid-term meetings will be scheduled. Management of large

development projects, on the other hand, will follow the rigorous processes established for SKA

construction work packages, drawing on programmes staff with support from SKAO assurance,

finance, and procurement.

7.11 Funding Profile

The current expectation, based on interactions with the Board and CPTF, is that €40 M will be allocated

to the SODP over the first 10 years from the start of SKA construction, included within the total funding

from members to SKAO to deliver the SKA-1 Construction Proposal and the Observatory Establishment

and Delivery Plan. The long term SODP funding is then expected to be €20 M per year.

Factors affecting the profile of initial SODP funding are:

- the need to avoid disruption of other SKAO activities, which argues that major projects should
  not be started until after the formal end of construction;
- alignment with external funding sources, which run on different cadences;
• the long lead time required to prepare a strong proposal, including building a science case, performing preparatory design work and estimating costs; and
• the wish to maintain continuity in design groups contributing to SKA.

These considerations argue for a phased approach, with a relatively early start to studies, but funding of large projects only in years 9 and 10. This will also allow for the restoration of any deferred capability shortly after the end of construction. In steady-state, the anticipated budget of €20 M/year is notionally divided between €18.5 M for projects and €1.5 M for studies. The proposed funding profile is shown in the following table.

Table 38: Funding profile for the SKA Observatory Development Programme.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cost (€ M)</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>Road map and plan process starts.</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>Initial draft road maps and development plan made available by SKAO. Deadline for study cycle 1 proposals.</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Study cycle 1.</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Study cycle 1 (continued); deadline for study cycle 2 proposals.</td>
</tr>
<tr>
<td>5</td>
<td>1.5</td>
<td>Study cycle 2.</td>
</tr>
<tr>
<td>6</td>
<td>1.5</td>
<td>Study cycle 2 (continued); deadline for study cycle 3 proposals.</td>
</tr>
<tr>
<td>7</td>
<td>1.5</td>
<td>Study cycle 3 (project preparation).</td>
</tr>
<tr>
<td>8</td>
<td>1.5</td>
<td>Study cycle 3 (continued); approved development plan available. Deadlines for study cycle 4 and project cycle 1.</td>
</tr>
<tr>
<td>9</td>
<td>12</td>
<td>Project cycle 1.</td>
</tr>
<tr>
<td>10</td>
<td>18</td>
<td>Project cycle 1 (continued).</td>
</tr>
<tr>
<td>11+</td>
<td>18.5</td>
<td>Projects.</td>
</tr>
<tr>
<td>(steady-state)</td>
<td>1.5</td>
<td>Studies.</td>
</tr>
</tbody>
</table>

It is likely that a small fraction of the budget will be used to support community involvement in planning, particularly through workshops and road map development meetings.
8 Observatory Staffing and Costs

This section specifies the resources required to deliver this plan. The staffing profiles are presented for the 10-year period 2021-30, with the assumed start of construction in 2021 through to the end of construction in 2028, and the first two years of the operations phase of the SKA Observatory. Costs across the four budget lines outlined in §1.2 are presented.

The estimated costs of construction support correspond to delivery of the design baseline of the SKA1 telescopes [AD4] and are covered in detail in the companion Construction Proposal [RD1].

8.1 Staffing Profile

The current estimate of the staffing profile (headcount) across the three host countries and for the three employers of SKA staff is given in the table below.

Table 39: Staffing profile (FTE) for the SKA Observatory by location and by employer (across all four budgets).

<table>
<thead>
<tr>
<th>Country</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>133.1</td>
<td>150.4</td>
<td>150.4</td>
<td>156.4</td>
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<td>AUS</td>
<td>10</td>
<td>44.3</td>
<td>60.6</td>
<td>79.5</td>
<td>100</td>
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<td>134.3</td>
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<td>135.5</td>
<td>128</td>
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<tr>
<td>RSA</td>
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<td>TOTAL</td>
<td>153.6</td>
<td>246.4</td>
<td>276.6</td>
<td>318.4</td>
<td>374.9</td>
<td>422.9</td>
<td>459.9</td>
<td>450.1</td>
<td>430.9</td>
<td>415.9</td>
</tr>
</tbody>
</table>

Note that the transition between construction and operations phases requires that some construction support staff remain employed between 2028-29. During this time, they are budgeted for in the Observatory operations budget and as such, the year 2030 is more representative of "steady-state operations" than any previous years.

8.2 Basis of Estimates

The basis of the estimates used to arrive at the costs presented in this revision of the SKA operations plan is:

- salaries are calculated using 2020 GBP, AUD, or ZAR benchmark salaries, and converted to Euros;
- non-staff costs have been estimated using 2020 Euros;
- operations and maintenance costs for the SKA telescope elements’ hardware and software components were estimated by the design consortia using 2017 Euros escalated to 2020 Euros, and are as presented for their critical design reviews; and
- no future inflationary escalation has been accounted for.
8.3 Estimation of Staffing Costs

The currently estimated staff costs are presented in the table below. Current remuneration rates have been assumed to continue into the IGO-era. On-costs are set at 45% for SKAO employees. On-costs for CSIRO and SARAO employees are set at 30%, and indirect costs are set at 15%, both of which are included in the staff costs. The on-costs have been aligned to current practices at CSIRO and SARAO, however, the methodology for calculating indirect costs is still not formally agreed and there is some uncertainty around this number.

Table 40: Staff costs for the SKA Observatory by location and employer.

<table>
<thead>
<tr>
<th>€ (M)</th>
<th>Construction</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2021</td>
<td>2022</td>
</tr>
<tr>
<td>Country</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>15.8</td>
<td>17.0</td>
</tr>
<tr>
<td>AUS</td>
<td>1.3</td>
<td>5.2</td>
</tr>
<tr>
<td>RSA</td>
<td>1.0</td>
<td>3.6</td>
</tr>
<tr>
<td>TOTAL</td>
<td>18.1</td>
<td>25.8</td>
</tr>
<tr>
<td>Employer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKAO</td>
<td>16.9</td>
<td>19.5</td>
</tr>
<tr>
<td>CSIRO</td>
<td>0.7</td>
<td>3.8</td>
</tr>
<tr>
<td>SARAO</td>
<td>0.5</td>
<td>2.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>18.1</td>
<td>25.8</td>
</tr>
</tbody>
</table>

The breakdown of staff costs by budget area is shown in the table below. Staff supporting the Observatory Development Program are accounted for under other budget areas.

Table 41: Staff costs for the SKA Observatory by budget area.

<table>
<thead>
<tr>
<th>€ (M)</th>
<th>Construction</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2021</td>
<td>2022</td>
</tr>
<tr>
<td>Observation Support</td>
<td>5.5</td>
<td>11.5</td>
</tr>
<tr>
<td>Observatory Operations</td>
<td>6.3</td>
<td>5.7</td>
</tr>
<tr>
<td>Business Enabling</td>
<td>6.3</td>
<td>8.6</td>
</tr>
<tr>
<td>TOTAL</td>
<td>18.1</td>
<td>25.8</td>
</tr>
</tbody>
</table>

8.4 Estimation of Non-Staff Costs

The currently estimated non-staff cost profile, broken down by “location”, is presented in the table below. These costs are presented as:

- those costs for activities across the SKA Observatory as a whole (e.g., SAFe Programme Increments, IT);
- those costs which are specific to one of the three locations; and
- the Observatory Development Program.
Table 42: Estimated non-staff costs for the Observatory.

<table>
<thead>
<tr>
<th>Location</th>
<th>Amount (€ M)</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKA Observatory</td>
<td></td>
<td>8.3</td>
<td>14.1</td>
<td>17.9</td>
<td>19.4</td>
<td>21.2</td>
<td>23.0</td>
<td>25.5</td>
<td>26.1</td>
<td>36.9</td>
<td>42.8</td>
</tr>
<tr>
<td>UK</td>
<td></td>
<td>1.4</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>1.0</td>
<td>0.9</td>
<td>0.9</td>
<td>0.8</td>
<td>1.1</td>
<td>0.8</td>
</tr>
<tr>
<td>AUS</td>
<td></td>
<td>0.1</td>
<td>1.9</td>
<td>4.7</td>
<td>8.3</td>
<td>11.5</td>
<td>17.2</td>
<td>19.0</td>
<td>20.8</td>
<td>20.6</td>
<td>21.0</td>
</tr>
<tr>
<td>RSA</td>
<td></td>
<td>0.05</td>
<td>2.1</td>
<td>5.0</td>
<td>7.9</td>
<td>12.1</td>
<td>17.1</td>
<td>19.0</td>
<td>21.8</td>
<td>20.9</td>
<td>20.2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>9.8</td>
<td>18.9</td>
<td>28.4</td>
<td>36.4</td>
<td>45.8</td>
<td>58.2</td>
<td>64.4</td>
<td>69.5</td>
<td>79.5</td>
<td>84.8</td>
</tr>
</tbody>
</table>

The non-staff costs within each of the four budget areas (§1.2) are presented in the table below.

Table 43: Estimated non-staff costs against the four budgetary areas for the Observatory.

<table>
<thead>
<tr>
<th>Budget</th>
<th>Amount (€ M)</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Support</td>
<td></td>
<td>2.1</td>
<td>5.6</td>
<td>3.8</td>
<td>3.8</td>
<td>3.8</td>
<td>3.8</td>
<td>3.2</td>
<td>1.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Observatory Operations</td>
<td></td>
<td>0.5</td>
<td>3.3</td>
<td>13.5</td>
<td>20.0</td>
<td>27.1</td>
<td>38.1</td>
<td>42.0</td>
<td>47.0</td>
<td>48.0</td>
<td>47.6</td>
</tr>
<tr>
<td>Business Enabling</td>
<td></td>
<td>7.2</td>
<td>10.0</td>
<td>10.2</td>
<td>11.6</td>
<td>13.3</td>
<td>14.8</td>
<td>17.6</td>
<td>19.6</td>
<td>18.5</td>
<td>18.2</td>
</tr>
<tr>
<td>Observatory Development</td>
<td></td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>13</td>
<td>19</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>9.8</td>
<td>18.9</td>
<td>28.5</td>
<td>36.4</td>
<td>45.8</td>
<td>58.2</td>
<td>64.4</td>
<td>69.6</td>
<td>79.5</td>
<td>84.8</td>
</tr>
</tbody>
</table>

The budget lines that dominate the non-staff costs once the Observatory has more-or-less achieved routine operations, i.e., in the year 2030, are shown in Table 44. All items that contribute more than €3.0 M/year to the budget in the year 2030 are shown.

Table 44: Ranked order of the largest sources contributing to the non-staff costs in routine operations.

<table>
<thead>
<tr>
<th>Item</th>
<th>Total (€ M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>14.8</td>
</tr>
<tr>
<td>MID Operations &amp; Maintenance</td>
<td>7.8</td>
</tr>
<tr>
<td>LOW Operations &amp; Maintenance</td>
<td>6.0</td>
</tr>
<tr>
<td>DG Contingency</td>
<td>5.0</td>
</tr>
<tr>
<td>Travel</td>
<td>4.3</td>
</tr>
<tr>
<td>IT &amp; Networks</td>
<td>4.2</td>
</tr>
<tr>
<td>Host Country Facilities</td>
<td>4.2</td>
</tr>
<tr>
<td>Compute Refresh</td>
<td>3.8</td>
</tr>
</tbody>
</table>

8.4.1 Power Cost Estimate

Power for the telescope sites and the science processing centres is by far the costliest non-staff item for the SKA, and the total power cost dominates the non-staff budget (see Table 44). The power cost used in this plan is the average of the costs associated with using power from the grid where available and from diesel generators where no grid connection is possible, and the (lower) cost based on industry responses to SKA requests for information in South Africa and Australia which resulted in
options with cheaper high-penetration renewables-based generation options. The steps are outlined in the following subsections.

8.4.1.1 Baseline – Grid/Diesel Power

The baseline power cost calculation is outlined in Table 45.

Table 45: Baseline power cost.

<table>
<thead>
<tr>
<th>Telescope</th>
<th>Location</th>
<th>Rate ($/kWh)</th>
<th>Consumption (kW)</th>
<th>Annual cost ($ M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKA1-LOW</td>
<td>Site</td>
<td>0.34</td>
<td>3300</td>
<td>9.8</td>
</tr>
<tr>
<td></td>
<td>SPC</td>
<td>0.12</td>
<td>1900</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SKA1-LOW TOTAL</td>
</tr>
<tr>
<td>SKA1-MID</td>
<td>Site</td>
<td>0.12</td>
<td>4220</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>DRUPS</td>
<td></td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Remote PV</td>
<td></td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>SPC</td>
<td>0.12</td>
<td>1700</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SKA1-MID TOTAL</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TOTAL</td>
</tr>
</tbody>
</table>

The baseline rates in Table 45 are derived using current industry expectations for the next 10 years in Australia and South Africa. In South Africa, there is already grid power being delivered to the site and the tariff for its consumption is estimated to be €0.12 kW/hr, an average of the daytime (€0.18 kWh) and night-time (€0.06 kWh) rates. An estimate is also given for the use of diesel rotary UPS (DRUPS) for when grid power is not available. The baseline design for the observatory has the use of PV stations for the most remote dishes along the spiral arms of SKA1-MID. In Australia, there is no provision of grid power at the MRO, and so the baseline assumption, for the purposes of costing in this revision of the operations plan, is the use of diesel generators. The two SPCs are located in Perth and Cape Town and will be drawing power from the relevant city grid.

The baseline cost profile of power for the SKA1-LOW and SKA1-MID telescopes over the 10-year period covered by this plan, based on these conservative assumptions, is shown in Table 46. The profile through the construction phase is scaled against the expected size of the arrays at that time.

8.4.1.2 Hybrid Power

SKA intends to source a substantial fraction of its electricity from more sustainable (primarily photovoltaic solar) generation.

The SKA Power Engineer has made a comparative study of possible cost savings if the SKA Observatory were to pursue a hybrid power solution, including formal request for Information processes in both Australia and South Africa that have resulted in detailed responses from the respective power industries. In South Africa, the most favourable model uses renewable (PV solar + battery) energy during the day, when grid power is generally more expensive and reverts to grid/diesel power during the night when power from the grid is cheaper and the solar source is not available. In Australia,

\[^{25}\] At the time of writing, the cost of using batteries to store energy for night-time use in South Africa is expected to be more expensive than the cost of grid power.
where grid power is not available at the site of the SKA1-LOW antennas, the model assumes power from a PV station with a substantial battery bank together with diesel generators as backup during the night and periods of low solar irradiation. For both SKA1-MID and SKA1-LOW, a number of antennas/stations at the outer ends of the spiral arms will be powered by remote generator stations, most likely using a combination of PV and batteries.

Table 46: Baseline cost profile for the delivery of power to the telescope sites and the science processor centres.

<table>
<thead>
<tr>
<th>Location</th>
<th>Amount (€ M)</th>
<th>Construction</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2021</td>
<td>2022</td>
<td>2023</td>
</tr>
<tr>
<td>SKA1-LOW</td>
<td>Site</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>SPC</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Total LOW</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SKA1-MID</td>
<td>Site</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>DRUPS</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Remote PV</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>SPC</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Total MID</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Using the same power consumption for the SPCs and the telescope sites as in the costings presented in Table 45, and estimating power tariffs for renewable energy based on the model described above and using industry submissions in response to SKA request for information processes, the cost of powering the telescope sites, and the SPCs in Australia and South Africa were calculated for the operational phase of the SKA Observatory. The result of this study is shown in Table 47, along with the potential saving over those presented in Table 45.

This study has shown that a hybrid solution for powering the telescope sites and the SPCs could potentially realise a 40% saving on the annual cost of power relative to the current estimate.

Table 47: Cost estimates, during the operations phase, for a hybrid power solution that includes renewable energy, and the associated savings relative to the current baseline (Table 46).

<table>
<thead>
<tr>
<th>Telescope</th>
<th>Location</th>
<th>Rate (€/kWh)</th>
<th>Consumption (kW)</th>
<th>Annual cost (€ M)</th>
<th>Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKA1-LOW</td>
<td>Site</td>
<td>0.18</td>
<td>3300</td>
<td>5.2</td>
<td>47%</td>
</tr>
<tr>
<td></td>
<td>SPC</td>
<td>0.12</td>
<td>1900</td>
<td>2.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>7.2</td>
<td>39%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKA1-MID</td>
<td>Site</td>
<td>0.06</td>
<td>4220</td>
<td>2.2</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>DRUPS</td>
<td></td>
<td></td>
<td>0.2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Remote PV</td>
<td></td>
<td></td>
<td>0.2</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>SPC</td>
<td>0.06</td>
<td>1700</td>
<td>0.9</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>3.5</td>
<td>47%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL POWER</td>
<td></td>
<td></td>
<td>10.7</td>
<td>42%</td>
<td></td>
</tr>
</tbody>
</table>

The SKAO is actively pursuing further industry engagement aimed at implementing power solutions in both Australia and South Africa that maximise the use of renewables and minimise cost over the life
of the Observatory. The SKA Power Engineer has developed a power procurement strategy and draft power procurement plans for each of SKA1-MID and SKA1-LOW. SKAO is working closely with colleagues from CSIRO and SARAO to refine and implement these plans, taking advantage of their extensive experience in the relevant national contexts. The power procurement plans involve the development of reference designs for PV/battery power generation stations and the necessary RFI shielding, that will complement the normal material to be provided in formal requests for proposals (RfPs) for power supply agreements that will be issued in both Australia and South Africa. The aim is to go to market with these RfPs in 2021/22.

8.4.1.3 Assumed Power Cost Savings

It is assumed that SKA will realise savings amounting to half the cost difference between the baseline power cost estimate and the hybrid power cost estimate outlined above. This is included as an explicit line item, calculated as a 20% reduction in power costs relative to the grid/diesel baseline, and amounting to a cost reduction of €19.6 M over this 10-year plan, and €3.6 M p.a. from 2028 onwards.

8.4.2 Data Network Costs

It is anticipated that the SKA Observatory will fund the initial dedicated links out of each site and into the Northern Hemisphere where data transport is more resilient and would not require dedicated links. The estimate presented in Table 48 shows the annual cost of those primary links out of each site (specifically, the SDP at the SPC) into the Northern Hemisphere (Singapore for SKA1-LOW, and UK for SKA1-MID).

Table 48: Network costs for data transfer links from the two SKA telescope sites into the global SRC network.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (€ M/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SKA1-LOW fibre connection, Perth – Singapore</td>
<td>0.9</td>
</tr>
<tr>
<td>SKA1-MID fibre connection, Cape Town – UK</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1.8</strong></td>
</tr>
</tbody>
</table>

A study of the global routes and network topology available is presented in [RD23]. The funding and operational model for data transport within the SRC network is being investigated as part of the SRC steering committee activities [RD24].

8.4.3 Travel

Staff travel is a significant component of the non-staff budget (see Table 49). The budget estimates the cost of staff travel based on an average expenditure scaled against the total staff headcount. This figure covers the cost of travel for:

- conferences and meetings for all staff across the Observatory; and
- occasional travel between the SOC (Perth and Cape Town) and the respective EOC and the telescope site for staff who are normally located at the SOC.

It is this generic element of the travel budget that will be subject to management decisions regarding how much travel is likely to be necessary, or how much the Observatory is prepared to spend.
The cost of travel at the two SKA telescope sites is primarily due to:

- SKA-LOW, FIFO (“fly-in, fly-out”) costs for travel from the EOC in Geraldton to the MRO;
- SKA-LOW, travel in vehicles between the EOC in Geraldton and the MRO; and
- SKA-MID engineering operations staff, the cost of flights between Cape Town to Carnarvon, for access to the EOC at Klerefontein and the SKA-MID telescope site.

In the case of SKA-MID, the senior engineering operations staff are likely to be located at the SOC in Cape Town (as is the current model for MeerKAT).

Table 49: Annual costs of travel for staff across the SKA Observatory (estimated for 2030).

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (€ M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staff Travel</td>
<td>3.3</td>
</tr>
<tr>
<td>Committees</td>
<td>0.1</td>
</tr>
<tr>
<td>SKA-LOW Travel</td>
<td>0.7</td>
</tr>
<tr>
<td>SKA-MID Travel</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>4.3</strong></td>
</tr>
</tbody>
</table>

8.4.4 Computer Hardware Refresh and Decommissioning Funds

The SKA Observatory convention states:

*The SKAO may establish a fund for future liabilities associated with construction, operation, upgrade and decommissioning.*

As such, two funds are being built during the early years of operation. These funds are for the refresh of the computer hardware and the eventual decommissioning of the SKA telescopes, including the restoration of those sites.

8.4.4.1 Computer Hardware Refresh

It is anticipated that at least some of the telescope components will have lifetimes as short as a few years, and obsolescence management is, therefore, key to their operational support (§6.4.6.16). This plan builds a hardware refresh fund from 2023 at €3.75 M/year. The SDP CDR stated that a refresh of the HPC hardware would be required 5-years after the full deployment of SDP, at a cost of approximately €24 M. A further €5 M is required for the refresh of other computer hardware (i.e., PSS, PST, TM, and networking hardware). Further study into the different refresh options will be undertaken as part of the hardware risk mitigation plan [RD19]. For now, a fund which provides a sum of €30 M by 2030 for a refresh of all computer hardware is assumed.

8.4.4.2 Decommissioning

The expected lifetime of the SKA Observatory is 50 years. This does not imply, however, that the SKA1-LOW and SKA1-MID telescopes being deployed in phase 1 of the project will operate unchanged for the entire 50-year period: they may be upgraded or replaced or even terminated, depending in part on the evolution of scientific priorities. Accordingly, the level-1 requirements to which the telescopes are being designed do not specify a 50-year lifetime. The hosting agreements state:

*SKAO shall ... be solely responsible for all aspects of the SKA project ... including ... decommissioning and restoration of the site.*
Decommissioning and site restoration are the final phase of the SKA project (Figure 34). The detailed requirements for this phase have not yet been established, and an implementation plan has therefore not yet been developed.

The fund to provide for decommissioning has been set to zero for the duration of the construction phase of the observatory, and then begins to build at €2 M/year during the operations phase, starting in 2029.

8.5 Cost Risks

There are inherent risks associated with the budgets presented. In particular, there is no future escalation to take into account increasing costs due to:

- inflation; and
- exchange rate fluctuations.

All costings have been estimated at 2020 valuation. Future inflationary increases in costs are expected to be covered by the escalation of funding from members.

Exchange rates used in the budgets are 12-month average rates, as follows:

<table>
<thead>
<tr>
<th>Currency</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>USD</td>
<td>1.12</td>
</tr>
<tr>
<td>GBP</td>
<td>0.87813</td>
</tr>
<tr>
<td>SEK</td>
<td>10.6589</td>
</tr>
<tr>
<td>AUD</td>
<td>1.6486</td>
</tr>
<tr>
<td>CAD</td>
<td>1.4833</td>
</tr>
<tr>
<td>CNY</td>
<td>7.7749</td>
</tr>
<tr>
<td>INR</td>
<td>80.0292</td>
</tr>
<tr>
<td>NZD</td>
<td>1.7376</td>
</tr>
<tr>
<td>ZAR</td>
<td>17.2495</td>
</tr>
</tbody>
</table>


To manage short-term and moderate-scale variations as a result of inflation and exchange rate variations, as well as the realisation of other risks, the DG will hold a contingency line in the budget, which ramps up to €5 M/year in the last four years of this plan. However, major or long-term inflation or variations in exchange rates cannot reasonably be managed by the Observatory alone and would need to be addressed by the Council and members.

8.6 Cost Summary

Table 50 provides an overall summary of the non-capital cost for SKA1 for the period 2021-30. The 10-year non-capital cost for the SKA Observatory is estimated to be €704.4 M, including €40 M for the Observatory Development Program. Numbers are rounded where necessary to the nearest €0.1 M, so sums are approximate.
Table 50: Estimated overall Observatory cost, excluding the capital cost of construction of SKA1, and the cost of construction support.

<table>
<thead>
<tr>
<th>Location</th>
<th>Type</th>
<th>Amount (€ M)</th>
<th>Construction</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2021</td>
<td>2022</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>9.0</td>
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<tr>
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<td>9.4</td>
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<td>0.8</td>
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<tr>
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<td>3.0</td>
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<tr>
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<td>0.1</td>
<td>1.9</td>
</tr>
<tr>
<td>RSA</td>
<td>Staff</td>
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<td>1.8</td>
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<td></td>
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<td>0.05</td>
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<td>TOTAL</td>
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<td>20.2</td>
<td>27.6</td>
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9 Consolidated risk summary

In this section, we present the key cost uncertainties that apply to the overall plan. Risks that relate primarily to BE and to Observatory operations are addressed in Sections 5.7 and 6.7, respectively. Risks that are specifically relevant to the construction of SKA1 are dealt with in the Construction Proposal [RD1].

9.1 Contingency

Following recommendations from the analysis of OpsPlan02 by the incoming Director of Operations commissioned by the CPTF, and from the operations review of OpsPlan03 in April 2020, the Observatory budget includes a DG’s contingency of €5 M p.a. This line is included explicitly to ensure that the Observatory can manage non-construction risks, which will necessarily be significant through the challenging early years of the establishment and delivery of a facility as complex as SKA1. It may be appropriate to review the level of funds held for DG’s contingency after the first few years of steady-state operations in order to assess if it is sufficient or could be reduced in line with a reduction of risk. An appropriate time to consider such a step would likely be five years after the end of the period covered by this plan.

9.1.1 Provisions

A number of circumstances that may arise from time to time, but with a degree of unpredictability with respect to frequency and timing, are expected to be dealt with by allocating funds when necessary from the DG’s contingency, not by allocating an explicit budget line to such an item.

Such items identified to date are:

- response and repairs necessitated by extreme weather events;
- one-off measures to assist in the attraction or retention of individual staff with critical and unique skills; and
- salary equity adjustments.26

9.2 Known Cost Uncertainties

A small number of known cost uncertainties remain significant at the time of writing this plan.

The conversion of the staffing plan to the staffing costs in this plan contains significant uncertainties because the terms and conditions that the IGO will operate under are not yet determined, and nor are the salary scales and benefits that will apply to IGO staff. The expectation is that the salary for a given role will remain essentially unchanged through the transition from the company to the IGO – which is expected to occur during 2021 and that the shift to the job families and any associated salary and benefits changes will occur in 2022.

9.2.1 Salary Scales for SKAO Employees

A great deal of work is underway to identify job families that will be adopted by the Observatory and to cross-reference those job families and levels within them to comparable organisations, using Korn Ferry as external consultants in this field. When preparing the budgets, salaries have been estimated based on current salaries for roles that are expected to be filled by employees of SKA Organisation. Where a similar role does not currently exist, salaries have been benchmarked to the Korn Ferry

26 Initial cost from contingency. Subsequent years would be folded into relevant salary budget.
reference points for the grading level of that role within the job family. The SKAO Council will decide on the remuneration strategy, and only then will roles be able to be accurately mapped to the salaries that will apply over the period covered by this plan. Budgeted salaries currently approximate to the median salary benchmark for the majority of roles, but some more specialised roles have been costed at the upper quartile level. If the SKAO Council decides to set the pay strategy at the upper quartile benchmark for all staff, the total staff cost is expected to increase by €25 M–€30 M.

The transition of the SKA from the organisation to the Observatory is expected to occur in 2021, and the implementation of the job family structure and new rewards and benefits is expected to be implemented later, currently anticipated at the start of 2022.

9.2.2 On-Costs for SKAO Employees

The assumption made in this plan is that on-costs for SKAO employees will be 45% of base salary, higher than for the current SKA organisation (30%) but lower than for other science-related IGOs (80-90%). A pessimistic approach suggests that in the worst case where the cost of employing IGO staff turns out to be as high as for other relevant IGOs, these costs may have been underestimated by €69 M over the 10 years of the plan. The associated underestimate relative to the baseline of €123 M p.a. in steady-state operations is €6.2 M. If realised, this would amount to increases of 3.5% over the 10 years covered by the plan, and 5.1% in the final year of the plan and steady-state operations.

9.2.3 Staff Development

Over time, staff develop new capabilities and knowledge, and opportunities for advancement through grading levels is an important tool for staff retention. Provision for a 1% p.a. increase in staff costs has been included to account for this effect. This is on the low end of the norm for similar organisations – 1.5-2% is not unusual. If the actual cost necessary for appropriate staff retention is 2%, the increase in cost over the 10 years covered by this plan would be €13.6 M.

9.2.4 Observatory-Wide Risks

The SKA risk register identifies three extreme corporate risks:

- NEW Business continuity of SKA is impacted by the current COVID-19 pandemic.
- SKA 299 Ratification of the Observatory convention and UK HQ agreement by the requisite group of countries is delayed.
- SKA 300 Insufficient resources available from the members to enable the establishment of the SKA Observatory and construction of the agreed scope of SKA-1.

An extract from the SKA risk register showing all extreme and high rated corporate risks (as at May 2020) is presented in Appendix 1 including impacts and mitigations.

At the time of writing the global COVID-19 pandemic is causing major disruption across all the countries participating in SKA, and it exacerbates all these risks.
10 Acknowledgements

These documents are the culmination of years of effort by a diverse, global group of experts from a wide range of organisations, including present and former staff of the SKA Organisation, the many partner institutions, industry collaborators, the construction consortia, advisory and review committees, science working groups and SKA governance structures. We hope that all contributors are proud of the result and we sincerely thank them for their excellent input. Their involvement has been instrumental in shaping the Project as we prepare to move now from planning to implementation and to set up the SKA Observatory as an Intergovernmental Organisation.
11 Appendix 1: Extreme and High Observatory-Wide Risks

<table>
<thead>
<tr>
<th>SKA Risk ID</th>
<th>Risk Description</th>
<th>Impact</th>
<th>Potential Causes</th>
<th>Existing Controls</th>
<th>Probability</th>
<th>Impact</th>
<th>Risk Exposure</th>
<th>Action Plan Add Mit + Progress</th>
<th>Deliverable</th>
<th>Current status</th>
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<tbody>
<tr>
<td>NEW</td>
<td>Business continuity of SKA is impacted by the current COVID-19 pandemic.</td>
<td>Results in a range of risks to schedule, and/or cost, and/or scope, materialise.</td>
<td>Global political and economic climate impacts areas such as cost of doing business, availability of human capital, ability to travel, management of international logistics etc.</td>
<td>Scenario planning underway.</td>
<td>4</td>
<td>5</td>
<td>EXTREME</td>
<td>Scenario planning underway for discussion with CPTF and SKA board.</td>
<td>COVID-19 risk assessment and scenario planning.</td>
<td>Open</td>
</tr>
<tr>
<td>299</td>
<td>Ratification of the Observatory convention and UK HQ agreement by the requisite group of countries is delayed.</td>
<td>Establishment of the IGO is delayed and impacts transition and start of construction activity.</td>
<td>Ratification processes start later than expected and/or take longer than expected due to domestic processes.</td>
<td>Monitor progress through CPTF. SKA organisation to remain legal and operational entity for SKA into 2021 - business plan in development.</td>
<td>4</td>
<td>5</td>
<td>EXTREME</td>
<td>Encourage political support to expedite the ratification process and provide office support for members during the ratification process. Regular updates at CPTF. Member ratification processes complete by the Netherlands and South Africa. Final authorisation steps for Italy. Australia due to complete by June as are China and Portugal. UK ratification processes for HQA due to start 16 March. Delayed due to current COVID-19 situation. Processes started 21 April. Business plan for 2021 in development.</td>
<td>Completed ratification processes and notification started.</td>
<td>Realised</td>
</tr>
<tr>
<td>#</td>
<td>Issue Description</td>
<td>Action/Impact</td>
<td>Status</td>
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<tr>
<td>300</td>
<td>Insufficient resources available from the members to enable establishment of the SKA Observatory and construction of agreed scope of SKA1</td>
<td>Bi-lateral funding discussions with future SKA Observatory members and potential members on-going. Agreement to aim for funding to deliver design baseline at mid-term SKA BUCoard February 2020. SKA organisation business plan for 2021 in development.</td>
<td>Open</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>304</td>
<td>Difficulty in alignment between engineering and IGO schedules to establish SKA Observatory and approve start of construction.</td>
<td>Delay to ratification processes impacts construction schedule. Integrated plan to be updated to take account of revised governance plan.</td>
<td>Open</td>
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</tbody>
</table>

**Details:**

- **300:**
  - **Scope and/or construction schedule for SKA1 compromised**
  - Funding schedule does not yield sufficient resourcing. Current COVID-19 situation may impact level and/or timing of commitments.
  - Detailed analysis and bi-lateral discussion of each member's funding position to establish the likelihood and scale of any funding gap.
  - **Risk Level:** EXTREME

- **304:**
  - **Difficulty in alignment between engineering and IGO schedules to establish SKA Observatory and approve start of construction.**
  - Council of the SKA Observatory cannot meet before ratification processes complete and entry into force.
  - Co-ordination ongoing and integrated plan developed.
  - **Risk Level:** HIGH

**Appendix 1:**

- **200**
<table>
<thead>
<tr>
<th>ID</th>
<th>Description</th>
<th>Details</th>
<th>Control</th>
<th>Status</th>
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<tr>
<td>322</td>
<td>Lack of resources available for transition to plan, manage, and execute the transition from the SKA organisation to the SKA Observatory.</td>
<td>Delays to transition activities and processes may ultimately delay the establishment of the SKA Observatory IGO. Business as usual activities do not allow SKAO staff sufficient time to dedicate to transition activities in some key workstream areas such as HR, finance. Exacerbated by COVID-19 impact.</td>
<td>The transition plan informs the resources required to execute the transition activities. Activities are prioritised and reviewed through internal checkpointing with oversight from SKA Governance bodies.</td>
<td>3 4</td>
</tr>
</tbody>
</table>

SKA business plan for 2020 provides resources required within the SKA Office for transition delivery. Additional consideration given to securing external consultancy/contractors as appropriate, e.g., finance, HR, etc.

While transition activities continue COVID-19 has impacted near term deliverables and replanning is underway to align activities to revised governance schedule.

Revised transition plan.

Open