SKA1 OPERATIONAL CONCEPT DOCUMENT

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LIST OF ABBREVIATIONS

A&A ....Authorisation & Authentication
API.................................Application Program Interface
ASKAP ....Australian SKA Pathfinder
AUS ....Australia
CSP ....Central Signal Processor
FoP................................Friend of Project
GHQ ....Global Headquarters
GSM ....Global Sky Model
KSP ....Key Science Project
LRU ....Line Replaceable Unit
NASA.............................National Aeronautics and Space Administration
PDF ....Portable Document Format
PI ....Principal Investigator
PSF ....Point Spread Function
QA ....Quality Assurance
RSA ....Republic of South Africa
RSDC ....Regional Science and Data Centre
SDP ....Science Data Processor
SKA ....Square Kilometre Array
SKA1 ....SKA Phase 1
SKA2 ....SKA Phase 2
SKAO ....SKA Observatory
TBD ....To Be Determined
TM ....Telescope Manager
ToO ....Target of Opportunity
VDIF ....VLBI Data Interchange Format
VLBI...............................Very Long Baseline Interferometry
VO ....Virtual Observatory

1 Introduction

1.1 Purpose of the document

This document defines the operational concept for the SKA1 Observatory. It draws significantly from the *Concept of Operations for the SKA Observatory* [RD1]. In contrast with [RD1], however, this document is narrower in scope and aims to provide sufficient detail for the derivation of Level-1 design requirements.

This focus of this document is on definition of the operational concept, not on its implementation. The implementation of observatory operations will be the subject of an Operations Plan, yet to be written.

The chronology of the project has resulted in a situation in which this document is being produced after the Level-1 design requirements are already in place, and after the design consortia have already derived their own lower-level requirements. Any new requirements arising from this document will therefore have to be implemented through the Engineering Change Proposal process. Consequently, none of the requirements in this document are binding upon the project until this process has been completed. The Level-1 System Requirements [AD1] will remain the definitive statement of what is to be delivered by the design project. Further details are provided in §3.3.

1.2 Scope of the document

This document defines the operational concept for Phase 1 of the SKA Observatory (SKAO hereafter), encompassing both SKA1-LOW and SKA1-MID. It does not include the operation of ASKAP, which, at the time of writing, may or may not be incorporated within the SKA. It also does not include the operation of SKA2, the scope of which is not yet defined, although it is anticipated that the operational concept defined here should be easily extensible to expanded versions of LOW and MID. It also does not include any consideration of commissioning or early science; these will be the subject of future planning documents.

1.3 Verb convention

The verb *shall* is used whenever a statement is intended to be binding. The verb *will* is used to express an intent. 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-0000008 Rev 6C, SKA Phase 1 System Requirements Specification
[AD2] SKA-TEL-SKO-0000007 Rev 02, SKA1 Level 0 Science Requirements
[AD3] SKA-BD-14-08, SKA Hosting Agreements

2.2 Reference documents

The following documents are referenced in this document. In the event of conflict between the contents of the referenced documents and this document, **this document** shall take precedence.

[RD1] SKA-TEL-SKO-0000256 Rev 02, Concept of Operations for the SKA Observatory
[RD2] SKA-TEL.TM.OBSMGT-TMC-AR-03 Rev 1, Proposal Handling and Observation Preparation Options
[RD3] SKA-TEL-SKO-0000000 Rev DE, SKA1 Telescope Calibration Framework
[RD4] SKA-TEL-SKO-0000102 Rev 01, SKA RAM Allocation
[RD5] SKA-TEL-SKO-0000103 Rev 01, SKA Support Concept
[RD6] SKA-TEL-SKO-0000104 Rev 01, SKA Integrated Logistic Support Plan

3 Flowdown

3.1 Flowdown from Science Requirements

Those requirements from the *SKA1 Level-0 Science Requirements* [AD2] that have operational implications are listed below.

Table 1: *Science requirements with operational implications.*

SCI_REQ-47	SKA1-LOW shall provide single pointing and multi-pointing local imaging modes.
SCI_REQ-48	SKA1-MID shall provide single pointing and multi-pointing local imaging modes.
SCI_REQ-49	SKA1-LOW shall provide (search, timing, archive and VLBI) non-imaging observation modes.
SCI_REQ-50	SKA1-MID shall provide (search, timing, archive and VLBI) non-imaging observation modes.
SCI_REQ-51	SKA1-LOW shall provide (multi-pipeline, multi-sub-array, image/non-image and coordinated) commensal mode observations.
SCI_REQ-52	SKA1-MID shall provide (multi-pipeline, multi-sub-array, image/non-image and coordinated) commensal mode observations.
SCI_REQ-53	SKA1-LOW shall provide the capability to change observing modes within less than 5 seconds.
SCI_REQ-54	SKA1-MID shall provide the capability to change observing modes and/or bands within less than 5 seconds.

The last two requirements in this Table are the subject of ongoing engineering analysis, and are to be regarded as aspirational at present.

3.2 Flowdown from the Board

On 25th July 2013, the SKA Board approved a set of top-level principles governing SKA operations. These principles were amended slightly on 29th October 2013. The current principles are as follows:

The SKA Observatory

1. The SKA Observatory will consist of SKA Telescopes[1], local activities necessary for their operation, data processing and archive facilities and a Global Headquarters.
2. The SKA Observatory will be operated as a single organisation.
3. The purpose of the SKA Observatory will be to enable scientists to pursue world-leading scientific programmes, to organise and conduct improvements and upgrades of the SKA

[1] SKA Telescope: A single scientific instrument of the SKA that can operate as a coherent system independently of other telescopes, but which may share resources, including software, with other telescopes. In practical terms, SKA1-LOW and SKA1-MID are both considered SKA Telescopes, whilst the SKA Observatory is the global organisation as defined in this principle.

telescopes in order to provide and maintain facilities that are at the forefront of science and technology and to ensure the protection of the SKA sites for the SKA and future radio telescopes.

4. The scope of the SKA Observatory will be to provide, commission, maintain, and upgrade the SKA Telescopes, and to deliver, support and curate scientifically viable data from the telescopes.
5. The SKA Telescopes will be located within radio quiet zones provided by the Host Countries of South and Southern Africa and Australia.
6. The expected lifetime of the SKA Observatory is 50 years.
7. The SKA Observatory will be the technical design authority for the SKA Telescopes.
8. The primary success metric for the SKA Observatory will be the significance of its role in making fundamental scientific discoveries and facilitating overall scientific progress, expressed as high impact, peer-reviewed scientific papers using SKA data.
9. The scope of the Concept of Operations (ConOps) is the entire SKA Observatory.

Structure of the SKA Observatory

10. The SKA Observatory shall be led by a Director-General, who reports to the SKA Board of Directors.
11. The SKA Observatory shall operate a Global Headquarters (GHQ), which will have overall responsibility for the SKA Observatory.
12. The SKA Observatory shall establish a presence in the two Host Countries for the purpose of controlling SKA infrastructure and conducting SKA Operations in the Host Countries.
13. The SKA Board shall appoint an external body to provide independent advice to the Director-General on the planning and conduct of SKA operations and science. The members will be appointed on the basis of their scientific expertise and experience.
14. The SKA Board will control the SKA brand and the GHQ will implement policies on such branding.

SKA Operations

15. SKA Operations is the sum of all SKA activities that are centrally managed, and which are neither part of the SKA Construction Project[2], nor Planning Activities[3]. For this purpose, managed activities include those contracted out, provided in kind by agreement, or similar.
16. The host countries will have an obligation to protect the radio quiet zones for the SKA and future telescopes from outside transmissions and other telescopes on site to agreed standards. The SKA Observatory will have responsibility for control of self-interference from SKA telescopes.
17. The SKA Board will define the SKA Access Policy governing the right to propose for observations and to have access to archived data.
18. The Director-General will retain the final authority for time allocation, within the policy framework set by the Board.

[2] SKA Construction Project: Everything defined in the capital project plan. Anything not explicitly in the capital project plan is not part of Construction.

[3] SKA Planning Activities: The activities leading to the definition of the capital project plan (or a major phase of the plan), and the operations plan. Planning includes project definition, system engineering and design. It includes the Preparatory and Pre-Construction phases of the project schedule, and any of the planning activities that are required for SKA2.

19. The SKA Observatory will be designed to accommodate a mix of large co-ordinated observations proposed by large teams and short PI-driven programmes.
20. The SKA Observatory will calibrate SKA data and make science-ready[4] data and ancillary products available to the users.
21. The SKA Observatory will provide an archive with a data management system to support data-intensive astronomy.
22. The SKA Observatory will provide user support and tools to enable exploitation of SKA data.

Incorporation of Precursors

23. Maximal use will be made of the precursor telescope sub-systems, infrastructure and components, based on cost-benefit analyses.
24. Disruption to the precursor science programmes will be minimised while expediting the build-out of SKA Phase 1 at both sites.

In May 2014, the SKA Board approved a set of 5 top-level principles governing access to the SKA, namely:

- that access should be based on scientific merit for scientists within the member states, evaluated through a single time-allocation process;
- that there should be a mechanism to ensure access is proportional to contribution level for each member state;
- that provision should be made to enable limited access for scientists from non-member states at a level TBD;
- that all data and data products should be made globally available after a suitable proprietary period; and
- that the Director-General will formally allocate time.

The operational model described in this document is subject to all of the above principles of operations and access. At the time of writing, an operations and access policy document is being developed as part of the international negotiation towards an Intergovernmental Organisation; until that process is complete, these principles are subject to change.

3.3 Relationship to Level-1 Requirements

At the time of writing this document, the Level-1 System Requirements already exist and are under configuration control [AD1]. The following relationships will therefore apply:

- operational requirements in this document that are already incorporated in the design of SKA1 through an existing Level-1 requirement are identified as such, and the relevant requirements are cited;
- operational requirements in this document that are not covered by an existing Level-1 requirement, or that contradict an existing Level-1 requirement, are identified as such. An Engineering Change Proposal will be generated to change the existing, or create a new, Level-1 requirement.

[4] The precise definition of science-ready data products is the subject of ongoing discussion as part of the design process.

As a consequence, none of the operational requirements listed in this document are binding upon the project until accepted through the change process. The Level-1 System Requirements will remain the definitive statement of what is to be delivered by the design project.

The Engineering Change Proposal process adopted by the SKA Project involves a consultative and detailed assessment of the impact of the proposed change (science, cost, schedule, performance, risk, etc.). It is possible that the change process may reject some of the requirements proposed herein on the grounds of incompatibility with the current design or because they would require significant re-work; this is a known risk, and reflects the chronology of the project.

New requirements that are approved through the change process will be ingested into the Level-1 requirements and a new version issued. During this ingestion process they will be allocated to design consortia or to the SKA Office.

4 Operational Success Metrics

The operational model described in this document is designed to maximise the operational success of the SKA Observatory. Success, in this context, is defined by the metrics described in this section.

4.1 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, subject to defined acceptance criteria including peer review, 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;
- the number of citations to included publications is a measure of scientific impact. This metric will be tabulated as required, primarily through web services such as the NASA Astrophysical Data System;
- the number of publications or citations per unit cost is a measure of value for money.

This list is not exhaustive, and may evolve over time; it nevertheless encapsulates the primary drivers for the operational model.

These metrics can be analysed with different amounts of granularity: e.g., over-subscription per member state, or number of publications per telescope (LOW/MID) or per 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.

4.2 Operational success metrics

Scientific success and operational success are intimately linked: a highly-efficient observatory, for example, will enable more science time on sky, which should in turn produce more science papers per unit time.

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

- system down time due to faults;
- system down time due to unavailability of computational resources;
- system down time due to planned maintenance;
- operational availability;
- operational availability of specific capabilities (specific bands and specific observing modes);
- observing efficiency (integration time per unit available time);
- observing project completion; and
- safety record.

This list is not exhaustive, and may evolve over time; it nevertheless encapsulates the primary drivers for the operational model.

High scientific impact often results from the exploitation of unique observational capabilities. The SKA will offer such unique capabilities from the outset, primarily due to the large increase in collecting area over existing facilities and the opportunity for multiplexing observations (§6.2.4). In order to maintain this leading position, a vigorous SKA Observatory Development Programme will be implemented during the operations phase. This programme will provide the Observatory with a steady flow of upgrades to existing capabilities and new capabilities, commensurate with the evolving ambitions of the SKA user community.

5 Operating Constraints

In this section, several factors that limit or constrain the operation of SKA1 are presented.

5.1 Hosting Agreements

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

- a Global Headquarters (GHQ) situated at Jodrell Bank Observatory, UK;
- SKA1-LOW, an array of dipole antennas at the Murchison Radio Observatory in Western Australia, along with on-site support facilities; and
- SKA1-MID, an array of dishes in the Karoo, South Africa, along with on-site support facilities.

In addition, there will be establishments elsewhere in Australia and South Africa that will provide scientific and technical support for SKA1 operations.

It is anticipated, at the time of writing, that the SKA Observatory will be created as an Intergovernmental Organisation before SKA1 operations commence. Activities and obligations in the UK, Australia and South Africa will be constrained by and subject to Hosting Agreements with these three countries.

These Agreements [AD3] are currently being negotiated. Under the current drafts, the SKA Observatory (or its agents) will have the following obligations:

- compliance with relevant laws and regulations in the host countries;
- compliance with regulatory and approval processes, including (but not limited to) environmental approvals;
- compliance with local and national workplace health and safety laws;
- provision of adequate insurance cover for the telescopes, works, staff, contractors, assets and infrastructure;
- insurance, repair, maintenance and replacement of assets and infrastructure provided by the host countries; and
- responsibility for any loss or damage to the sites.

Table 2: *Operational requirements (Hosting Agreements)*

No.	Requirement	Level 1 Status
SKA1-OPS-01	SKA1 operations in AUS/RSA shall comply with the relevant Hosting Agreement.	Requirements SKA1-SYS_REQ_2460 and SKA1-SYS_REQ_2484 require compliance with local and national laws for health & safety and environment, respectively. Additional requirements may be needed to capture the full scope of obligations under the Hosting Agreements.

5.2 Safety, Health and Environment

The Hosting Agreements require that all SKA1 operations be subject to applicable legislation in the three host countries; this includes, *inter alia*, occupational health and safety and environmental management (§5.1). In addition, the two telescope sites are remote and working conditions can be hazardous; special considerations, in excess of the requirements in the Hosting Agreements, will apply to ensure that safe and healthy working environments are provided.

The SKAO will issue a Safety, Health and Environment policy. The policy will, in general, conform to the most stringent regulatory regime of the three host jurisdictions. Compliance with the SKAO's policy will be required for all SKAO staff and its agents, contractors and visitors.

Table 3: *Operational requirements (Safety, Health & Environment)*

No.	Requirement	Level 1 Status
SKA1-OPS-02	The SKAO shall issue a Safety, Health and Environment policy to be followed by all SKA offices, agents, contractors and visitors.	New requirement.
SKA1-OPS-03	All SKA offices, agents, contractors and visitors shall be required to comply with the SKAO Safety, Health and Environment policy.	New requirement.

5.3 Radio-quiet Environment

The SKA1 Telescopes will be located within radio-quiet zones in Australia and South Africa. These zones are a globally unique resource. Both countries have obligations through the Hosting Agreements 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 that may affect other facilities. The corresponding requirements are captured in Section 11 of [AD1] and are not repeated here.

6 Science Operations

6.1 General principles

The SKA will be the world's largest observatory in the cm- to m-wavelength range, greatly surpassing the current generation of telescopes in sensitivity, field of view and thus survey speed. The SKA is designed to be a high-impact and transformative observatory, operating under principles that will enable these ambitions. The SKA will be designed to operate for 24 hours every day to maximise its scientific impact and provide access to as much of the southern sky as possible throughout the year. To drive efficiency up and overhead down, the SKA will operate without observers at the telescope. It will run a flexible observing programme to allow the observatory to continue to be scientifically productive in the face of adverse circumstances (e.g. weather, faults, etc), and multiplex its observing programmes as much as feasibly possible. The SKA shall operate under the guiding principles outlined in §3.2 and in [RD1].

Table 4: *Operational requirements (general principles)*

No.	Requirement	Level 1 Status
SKA1-OPS-04	The SKA shall be designed to operate for 24 hours per day.	New requirement.
SKA1-OPS-05	The SKA shall observe in a flexible manner such that it will automatically switch to the next feasible observation.	New requirement.

6.2 Observing

6.2.1 Time accounting categories

A wide range of observing capability must be supported by the SKA to enable the scientific goals of the observatory and its community to be achieved. For the purposes of tracking the observatory's efficiency while doing so, the following time accounting categories shall be defined: Setup, Calibration, Science, Engineering, Fault, Weather and Other (see Figure 1). This establishes a clear demarcation of activities during a typical observing period. For instance, the Engineering category is to differentiate observations that are taken specifically for the purposes of engineering, maintenance, or commissioning activities. The time elapsed for these should be accounted for separately from that for obtaining Science or Calibration data, for instance. There are activities that may not produce data on disks but the time taken for those activities will need to be accounted for. It is important to properly label all data in the appropriate logs and databases (see also §6.11).

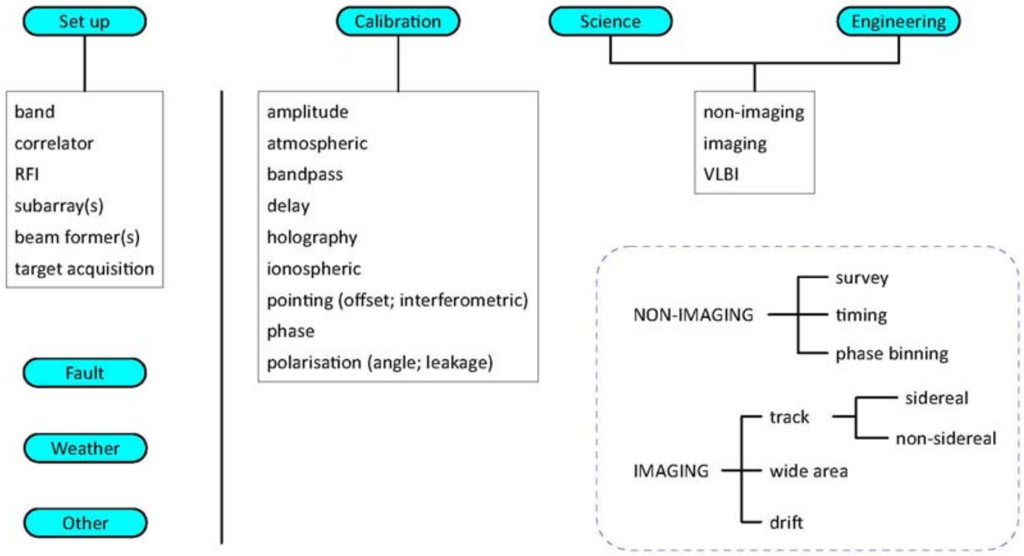

Figure 1: Time accounting categories (cyan boxes) showing some examples of the scans and other activities in those categories.

Table 5: *Operational requirements (time accounting categories)*

No.	Requirement	Level 1 Status
SKA1-OPS-06	Time accounting categories shall be defined for the SKA such that it will be possible to ascertain what the telescope's activity was at any point in time.	New requirement.
SKA1-OPS-07	SKA shall have an imaging capability that will obtain continuum and spectral-line data concurrently.	SKA1-SYS_REQ-2128
SKA1-OPS-08	SKA shall have the capability to search for fast (< 1 sec) and slow (seconds to hours) transients. The timing of the transients shall also be measured.	New requirement. Note that there are many Level 1 requirements in [AD1] that cover pulsar observations in more detail. This requirement ensures that this capability is available for any astronomical target. See also SCI_REQ-49 and SCI_REQ-50.
SKA1-OPS-09	SKA shall be able to acquire imaging data at a single, specified (RA, Dec) position on the sky, or of objects that move relative to the sky, e.g. planets.	New requirement. This pertains to sidereal and non-sidereal tracking. See also, SCI_REQ-47 and SCI-REQ-48 [AD2].
SKA1-OPS-10	SKA shall be able to acquire imaging data while the telescope is either driven across a range defined in (Az, El) or (RA, Dec) to build a map of the sky, or at a fixed (Az, El) position with data obtained as the sky drifts past the beam.	New requirement. See also, SCI_REQ-47 and SCI-REQ-48 [AD2].

6.2.2 Schedule blocks and scan types

It is useful at this point to define what a Schedule Block (SB), a Programme Block, and a scan mean in the context of this document, and how they relate to each other.

- Schedule Block (SB)
  - the SB is the atomic unit of planning and contains all information with respect to the telescope and instrument configurations
  - telescope/instrument configurations can only change at the SB level
  - observers interact with their project/observation design at the SB level (e.g. target lists, instrument/telescope configurations, calibration choices)
  - a SB should include all information necessary to enable a "science-ready" product (e.g. calibration requirements)
  - a SB should include all information necessary for it to be successfully (i.e. without error) executed at the telescope
  - SBs may have a range of durations
  - a SB executes on a subarray, which may include the full array (§6.2.5)
- Programme Block
  - a Programme Block allows for related SBs to be grouped (not just for organisational purposes)
  - the SBs in a Programme Block can be related by certain scheduling constraints,
    - SBs that need to be observed in a specific order
    - SBs that have specific scheduling constraints (e.g. near-simultaneous LOW/MID observing, or coordinated observations with non-SKA facilities)
- Scan
  - the scan is the atomic unit of execution
    - e.g. tracking a single source for a duration of 1-hr is an executable scan command
    - other commands will have configured the subarray, the instrument and ensured the pointing
  - a SB consists of one or more scans
    - long integrations can be built up by repeating a number of sequential scans (rather than repeating the SB)
    - if the scan or SB is interrupted and some time passes, then the SB will have to be repeated.
  - the system configuration is fixed during a scan

6.2.3 Target of opportunity and triggered events

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, transients), is an important science driver for the SKA. Thus, once an event has been triggered, it is important that the SKA is able to respond as quickly as possible by switching to the appropriate Schedule Block and acquiring the new target. The desired response time for LOW and MID is given in [AD2] – see also SCI-REQ-53 and SCI-REQ-54. At the time of writing, there have been no technical studies as to the feasible response times possible, and we await those studies before imposing a requirement on the system.

6.2.4 Commensal observing

Commensal observing will have a significant impact on the scientific productivity of the SKA. It is the ambition of the SKA to have commensal observing as a common-user capability, available for all projects. There are different kinds and levels of commensal observing:

- data commensality : more than one project can use the same data product(s), but with distinctly different science goals;
- observing commensality : more than one project can use the same field of sky, and telescope/instrument configuration, but they each need different data products;
- multiplexed commensality :
    - subarrays/tied-beam-arrays observe different fields of the sky with different instrument configurations;
    - different subarrays observe the same field of the sky but in different instrument configurations.

In the first, once the data are obtained the Science Data Processor (SDP) reduces them and the commensal projects are provided with access to the same data products. Limited data rights will be granted to each project to achieve the approved science goals, as recommended by the SKA Time Allocation Committee and approved by the Director-General. Each project is charged the integration time used, up to the limit of the time awarded by the time allocation committee. There is no sharing of time for commensal projects.

Whether the second and third type of commensality is feasible is dependent on the signal and data processing resources being available to generate the desired number of data products for each of the commensal projects (although note that commensality is also likely *within* projects).

Table 6: *Operational requirements (commensal observing)*

No.	Requirement	Level 1 Status
SKA1-OPS-11	SKA1 shall provide commensal observing for imaging and non-imaging modes.	A generalisation of: SKA1-SYS_REQ-2960 SKA1-SYS_REQ-2959 SCI_REQ-51 [AD2] SCI_REQ-52 [AD2]
SKA1-OPS-12	The SDP shall maintain a processing rate that keeps up with the average rate of data arrival.	New requirement.
SKA1-OPS-13	CSP and SDP shall report to TM, on request, the available signal and data processing resources.	New requirement.
SKA1-OPS-14	Data triggered by Target of Opportunity or other high priority events shall be prioritised for SDP processing at the first available opportunity.	New requirement.

6.2.5 Subarrays and tied-array-beams

There will be many projects for which the whole of the SKA1 (LOW or MID) array is not required to achieve the science goals of the project being observed, e.g. observing a very bright target or multiple objects across the sky. As described above, the SKA will be able to configure into subarrays and/or tied-array-beams to enable this multiplicity of observing.

Table 7: *Operational requirements (subarrays)*

No.	Requirement	Level 1 Status
SKA1-OPS-15	The SKA shall be able to form subarrays that can be configured and operated independently of each other.	Update to SKA1-SYS_REQ-2127. The restriction to 16 subarrays has been removed. At the time of writing, the upper limit on subarray capacity is one issue being considered by a Resolution Team. See also SCI_REQ-47 and SCI_REQ-48 [AD2].
SKA1-OPS-16	The SKA shall be able to form tied-array-beams that can will be configured and operated independently of each other.	Generalisation of several Level 1 requirements. Note that tied-array beams can only be formed within subarrays.
SKA1-OPS-17	Each subarray shall be able to receive and execute observing instructions assigned to it by the Telescope Manager.	New requirement.

6.2.6 VLBI

SKA1-MID will participate in VLBI observations. It is anticipated that proposals for using the SKA as part of the VLBI network will be peer reviewed for scientific merit and assessed for technical feasibility as part of the procedures established by a Global VLBI Consortium. Currently, no such consortium does exists, but for the purposes of this document, it is expected that a consortium will be established by the time SKA1 becomes operational.

It is anticipated that fixed blocks of observing time (sessions), of duration TBD, will be assigned for VLBI observing. VLBI projects will be submitted by the consortium in a format recognised by the SKA observation management system (see §6.4). There is in addition the possibility to have (fast) response VLBI observations for events that are time critical.

The Central Signal Processor (CSP) will provide functionality in order to form the VLBI beams and deliver the data in the standard VDIF data format. It will be a responsibility for SDP to store and/or stream the data for correlation elsewhere (at a VLBI processing centre, external to the SKA). No processing is required by SDP, apart from standard Quality Assurance (see §6.7). Relevant calibration information shall be made available.

It should be noted that the global VLBI consortium will need to establish a policy, with the SKAO, with regard to data rights.

Table 8: Operational requirements (VLBI)

No.	Requirement	Level 1 Status
SKA1-OPS-18	The SKA shall accept successful, peer-reviewed, VLBI projects. The format of the SKA VLBI data shall conform to standard VLBI formats.	New requirement.

The primarily technical requirements for VLBI are captured in Section 4.3.5 of [AD1] and are not repeated here.

6.3 Proposal submission and allocation of observing time

Telescope time is conventionally awarded to PIs via a two-phase process. First, the proposal is prepared, submitted, and peer reviewed. This includes a detailed technical description of the observations required. If the proposal is successful, it enters a second phase where technical details can be refined (perhaps following feedback, recommendations or restrictions from the time allocation committee). SKA users will, through a common, central utility, be able to prepare new and edit current proposals, and also to track their active and past projects, which may include initiating requests to retrieve data products from the archive (see Figure 2).

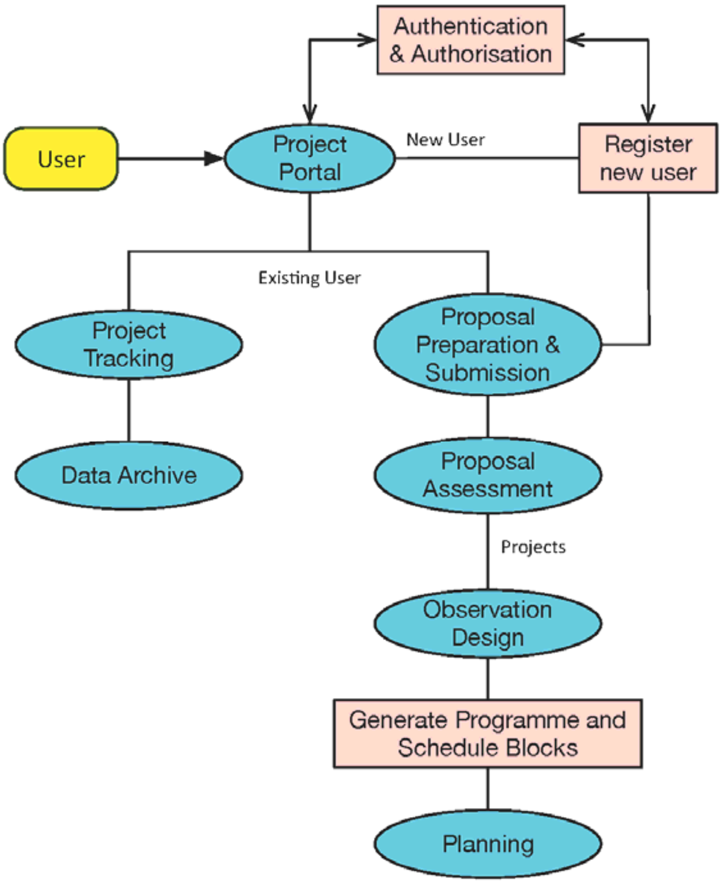

Figure 2: Overview of the lifetime of a proposal as it is prepared, submitted and becomes a project before it is observed at the telescope.

Operational principle 19 (§3.2) states that the Observatory will be designed to accommodate both large programmes and conventional PI-driven programmes. This section describes the process for proposal submission and time allocation for PI projects. The SKA scientific community is developing a suite of large programmes known as Key Science Projects (KSPs). It is expected that proposals for KSPs will follow similar principles, although the detailed process has yet to be determined.

6.3.1 Proposal submission

The SKA should not present a complicated proposal system to its potential users. All astronomers should be able to build a feasible scientific proposal without the need for specialist radio interferometry knowledge, although some radio astronomy knowledge must be assumed.

This section outlines the key requirements for a proposal submission system. This covers all activities up to and including the recommendation of an award of time by the time allocation committee, and the final confirmation of those recommendations by the Director General. Some of the functionality and processes described in this and following sections are described in further detail in [RD2].

Table 9: *Operational requirements (proposal submission)*

No.	Requirement	Level 1 Status
SKA1-OPS-19	A formal mechanism shall be available for SKA users to register for accounts to enable access rights to relevant resources and tools for managing their projects and proposals.	New requirement.
SKA1-OPS-20	Access shall be provided to SKA users to all information and correspondence on proposals and projects associated with them. This shall include functionality to create new accounts and new proposals, track progress on existing projects and access any associated data products.	New requirement.
SKA1-OPS-21	Proposal preparation and submission shall be possible using either a web or desktop-client system.	Update of SKA1-SYS_REQ-2647 and SKA1-SYS_REQ-2723.
SKA1-OPS-22	The PI of a proposal shall be able to delegate editing rights to Co-Investigators on the proposal.	New requirement.
SKA1-OPS-23	There shall be a centrally maintained and managed database for the SKA user to prepare and submit proposals, and to retain a full history of previous proposals.	New requirement.

The basic requirements for proposal preparation and submission include, *inter alia*, the functionality to generate accounts for PIs and co-Investigators, integration with an SKA Sensitivity Calculator, and access to astronomical databases to resolve names of astronomical objects and/or their coordinates. All relevant information of current and historical proposals shall be maintained in a central project database. To aid in the design of observations, the PI shall be able to access a library of standard template telescope configurations (e.g. pulsar timing, wide area scan, track) that can be copied into their proposals and tailored to their specific requirements. The PI will be able to delegate editing privileges to their Co-Investigators.

If the science goals of a proposal require the use of both LOW and MID, then it should be possible to request and justify the use of both telescopes within a single proposal. Two technical sections for each of LOW and MID will have to be included with the proposal.

Table 10: *Operational requirements (proposal submission functionality)*

No.	Requirement	Level 1 Status
SKA1-OPS-24	All relevant information regarding the telescope and instrument configurations shall be made available to aid users in constructing feasible proposals. This information shall be up to date at the time that the call for proposals is issued.	New requirement.
SKA1-OPS-25	There shall be a library of template configurations for users to browse and import into their proposals, and to tailor to their specific science objectives and requirements.	New requirement.
SKA1-OPS-26	There shall be an interface to a Sensitivity Calculator that will be used to determine an estimate of the total integration time needed to obtain a user-specified sensitivity, or vice-versa. The parameters and output of the Sensitivity Calculator shall be a part of the submitted proposal.	New requirement.
SKA1-OPS-27	Astronomical databases shall be accessible so that source names can be resolved and astronomical coordinates obtained. It shall also be possible to search for known sources around specified coordinates.	New requirement. (Although also see SKA1-SYS_REQ-2647)
SKA1-OPS-28	PDF files shall be accepted as submissions of the scientific and technical justifications.	New requirement.
SKA1-OPS-29	A proposal shall be able to request to use both SKA1-LOW and SKA1-MID within a single proposal. Separate technical descriptions for each telescope shall be included in the proposal.	New requirement.
SKA1-OPS-30	The contents of a proposal, including but not limited to technical configuration parameters, shall be verified against the known telescope and instrument constraints before a proposal is allowed to be submitted. The instrument and telescope constraints will be up to date at the time that the call for proposals is issued.	New requirement.

Key Science Projects will form a major part of the SKA science programme, with perhaps up to 70% of the available time dedicated to them. By definition, the full science goals of the KSPs can only be realised with the complete dataset. In the absence of any protection mechanism, there is a risk that the KSPs could be vulnerable to "cherry picking" of important targets. At the time of writing there is no policy in place governing the protection of KSPs from this. It is therefore assumed, for the purpose of this document, that PIs will be allowed to propose observations which overlap with approved KSPs as long as they can provide the scientific justification for doing so, demonstrating to the satisfaction of the time allocation committee that the scientific goals of the KSP(s) in question will not be compromised.

As such, there shall be a tool that will compare with the published KSP programmes and determine whether a PI proposal is in potential conflict, alerting the PI accordingly. The PI will have to justify in their proposal why no scientific conflict exists.

Table 11: *Operational requirements (KSP conflicts)*

No.	Requirement	Level 1 Status
SKA1-OPS-31	Observations defined in a proposal shall be compared to those published for Key Science Projects with potential conflicts identified and highlighted. This shall be part of the verification process (see SKA1-OPS-30).	New requirement.

It is well known that at many observatories there is a surge in proposal submission as one approaches the submission deadline. The submission system needs to be able to handle the load it will experience within the last few hours of the proposal submission deadline. It is expected that the load will be on all parts of the submission system.

Table 12: *Operational requirements (proposal submission system)*

No.	Requirement	Level 1 Status
SKA1-OPS-32	The proposal management system shall remain fully functional through peak load times, typically within 24 hours of the proposal deadline.	New requirement.

6.3.2 Scientific proposal review and time allocation

The time allocation process of the SKA shall be guided by the following basic principles:

- time allocation shall be driven by the scientific excellence of proposals;
- the time allocation process will be a fair process with the quality and importance of the submitted proposals informed by peer review;
- 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 programmes;
- the time allocation process shall preserve the anonymity and confidentiality of the referees (peer reviewers) who serve it; and
- the time allocation process will be robust against, and be able to resolve, conflicts of interest wherever they may arise.

The time allocation process will be managed and supported by Operations staff from SKAO. Given that the volume of proposals is expected to be high (even with KSPs in place) from across the SKA member nations, it is likely that the time allocation process will be split along defined science themes (TBD), with separate panels reviewing proposals submitted to each theme. As such, the grades assigned to proposals will be normalised so direct comparisons can be made across these thematic boundaries, and that a final merged ranking of all proposals can be constructed. This will allow comparisons to be made between different proposal cycles and as different personnel rotate on and off the thematic panels. In the following, “assessors” are individuals who are members of the time allocation committee(s).

Table 13: *Operational requirements (proposal assessment tools)*

No.	Requirement	Level 1 Status
SKA1-OPS-33	Authorised personnel shall be able to assign assessors and referees to each proposal, with invitations automatically issued to those assessors and referees.	New requirement.
SKA1-OPS-34	There shall be an interface for nominated referees and assessors to review and comment on proposals, and provide a numerical grade on the scientific justification for those proposals.	New requirement.
SKA1-OPS-35	There shall be an interface for authorised (usually SKA) staff to provide a technical report on the feasibility of a proposal.	New requirement.
SKA1-OPS-36	Grades assigned to proposals as part of the assessment process shall be collated and normalised across relevant boundaries, with a ranked list produced.	New requirement.
SKA1-OPS-37	There shall be an interface to provide feedback on each proposal, including a final grade and an indication of whether observing time has been awarded.	New requirement.

6.4 Observation Design

Successful proposals that have been granted time on the SKA then become Projects. As projects, they become the containers for all pertinent information related to them including, *inter alia*, scheduling blocks, observing logs, quality assurance (QA) record, project progress against allocation, associated calibrations, faults, and the environmental conditions during observations. There will also be a record of all communications to and from the PI regarding the project (when those communications are made while the PI is logged into the system – see Figure 2).

The PI, or their designate(s), shall be able to develop the detailed instrument and telescope configurations for each observation in their project. From this information, Schedule Blocks are generated.

Table 14: Operational requirements (observation design)

No.	Requirement	Level 1 Status
SKA1-OPS-38	The detailed preparation, design and adjustment of approved projects shall be possible via either a web or desktop-client system.	New requirement.
SKA1-OPS-39	All relevant technical information from an associated proposal shall be extracted from it to aid in designing the observing details of a project.	New requirement.

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 pipeline(s) that will be associated with the observed data. Refining the processing parameters will also be possible.

Table 15: Operational requirements (observation configuration)

No.	Requirement	Level 1 Status
SKA1-OPS-40	The technical configuration parameters of a project shall be verified against the known telescope and instrument constraints before a proposal is allowed to enter the project database. The instrument and telescope constraints shall be up to date at the time that the call for proposals is issued.	New requirement.
SKA1-OPS-41	There shall be a list of SDP pipelines, from which the PI should choose and associate to their project. A list of parameters to refine the SDP processing will also be accessible.	New requirement.
SKA1-OPS-42	Schedule Blocks for each verified project shall be generated and stored in a project database.	New requirement.

Note that it is expected that PIs will be carrying out the majority of the observation design for their projects during proposal preparation with help from Operations 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 the instrumentation and the observation preparation and design tools.

6.5 Observation sequencing and execution

6.5.1 Observation planning

In order for a telescope observing plan to be generated and executed, schedule blocks need to be in the database and available. Plans for each telescope can then be generated taking into account all known constraints. These can include any scheduled long-term maintenance or commissioning work, schedule blocks that need to be coordinated between the two SKA telescopes, or other known scheduling constraints (e.g. coordinating observations with other facilities). Operations staff can inspect this plan for any immediately obvious discrepancies, errors and inefficiencies before it is published and made available to the telescopes. Long, medium and short-term plans (of user-defined lengths) shall be constructed. The short-term plan will be the one that is executed at the telescope and be regularly updated.

Table 16: *Operational requirements (observation planning)*

No.	Requirement	Level 1 Status
SKA1-OPS-43	Verified observing plans will be generated for submitting to SKA1-MID and SKA1-LOW for execution.	New requirement to replace SKA1-SYS_REQ-2291 and SKA1-SYS_REQ-2292. Verification will be conducted by SKA Operations staff.
SKA1-OPS-44	Observing plans shall be constructed for both SKA1-MID and SKA1-LOW, taking into account all scheduling constraints, including due to coordination of schedule blocks between LOW and MID. These plans will be constructed for a user-specified length of time.	New requirement.
SKA1-OPS-45	An observing plan shall be simulated (faster than real-time) in order to verify its efficiency and performance.	SKA1-SYS_REQ-2294
SKA1-OPS-46	For the purposes of testing and investigating different scenarios, it shall be possible to construct an observing plan for a user-specified length of time, based on TBD constraints.	Update of SKA1-SYS_REQ-2293.

The Telescope Manager (TM) at the telescope sites needs to be aware of the maintenance schedule for each of SKA1-MID and SKA1-LOW and execute the plan in a flexible manner that fits both the scientific and current maintenance/engineering constraints (see §6.7). For instance, if the resources (e.g. the number of dishes or stations) are not available for the next item in the plan, then TM will automatically move to the next, issuing an alert to the Telescope Operator (see §6.10.2). For example, if there is maintenance scheduled of particular dishes/stations 4 hours into the future, TM should ensure that schedule blocks using those resources will complete within 4 hours.

It should be noted here that it is not just the maintenance schedule that the Telescope Manager needs sight of, but also the environmental conditions (e.g. ionospheric activity) and all relevant resources, especially SDP. TM needs to be able to either know[5] or predict the processing capacity the SDP has available before it sends the next observation(s) for execution. For instance, the SDP has a 6-hour buffer within which it needs to process all the data in that buffer. Thus, TM should not start to execute 6 commensal projects (in 6 subarrays, say) if each requires 3-4 hours of SDP processing time and there is only capacity to run 3 simultaneous pipelines, for example.

TM for each telescope should also be able to respond to any events that might be triggered (e.g. ToO, transients, VO Events) and change the short-term plan accordingly. Note that at the time of writing, a policy governing the implementation of ToO and VO Events is still TBD.

For the purposes of forward planning, Operations staff should be able to inspect a plan of a specified time range (e.g. the next 24 hours, week or month). This will allow staff to define/check/test/refine the observing programme for both the short and long-term (e.g. to cover long weekends, holidays, etc.) and investigate the impact to the productivity of the telescope under different scenarios, for example, losing half of an array due to some unforeseen event, or for other known, future maintenance.

Table 17: *Operational requirements (observation execution)*

No.	Requirement	Level 1 Status
SKA1-OPS-47	The Telescope Manager shall send Schedule Blocks for execution as long as the necessary resources are available to do so. If not, the schedule block is removed for execution at a later date, and the next best alternative in the plan is executed. The Telescope Operator shall be alerted when this occurs.	New requirement.
SKA1-OPS-48	The short-term plan shall dynamically adapt in response to any sanctioned ToO, VOEvents, or other approved triggers.	New requirement.

Once a scan has been executed the system will update the observing log (and thus the database). On completion of a Schedule Block, the database will also update the project and national completion rate.

[5] It is expected that it will be the SDP passing this information to TM upon request, rather than requiring TM to calculate this number.

Table 18: *Operational requirements (project accounting)*

No.	Requirement	Level 1 Status
SKA1-OPS-49	Once a Schedule Block has finished executing, the database will be updated with the Schedule Block's current status (i.e. completed or some other QA-based comment) and the project time accounting adjusted accordingly. This information shall pass to the relevant database so that the completed Schedule Block is no longer available (unless its status is changed manually by Operations staff following some review action).	New requirement.
SKA1-OPS-50	For completed Schedule Blocks that have been flagged as commensal, each associated project will be charged according to the time elapsed on their project. There will be no sharing of charged time.	New requirement.

6.5.2 Identifying commensality

Commensality will need to be identified during the planning stage. In particular, instances of data and observing commensality (see §6.2.4) will need to be appropriately flagged and packaged for execution, ensuring that the correct data products are associated with the correct projects. The position of the commensal group of projects in the short-term plan will be determined by the highest-ranked project in that group, i.e. that highest-ranked project should not have its position in the queue penalised by other projects that it happens to be commensal with. Of course, this is a boon for the lower ranked projects it is commensal with, but increases the scientific throughput of the observatory[6].

Table 19: *Operational requirements (commensality identification)*

No.	Requirement	Level 1 Status
SKA1-OPS-51	Schedule Blocks that can be observed commensally shall be identified during the planning stage.	New requirement.
SKA1-OPS-52	Commensal projects shall be appropriately packaged for execution at the telescopes. The corresponding data products shall be associated with the correct projects.	New requirement.
SKA1-OPS-53	Commensal schedule blocks will be placed in the telescope observing plans according to the highest-ranked project within the commensal group.	New requirement.

[6] Other methods for prioritising commensal projects may be devised in the future.

Note that commensal observing will result in more than 24 hours of observing time charged within a 24-hour period.

6.5.3 Manual operations

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

- by manually requesting inclusion of an engineering or other operation within the plan;
- by manually editing the plan to insert an automated operation at a future point in time (either schedule block or engineering operation);
- by performing manual low-level control of the telescope.

Other manual operation controls may be identified through the course of Integration & Verification that will need to be added.

Table 20: *Operational requirements (manual operation)*

No.	Requirement	Level 1 Status
SKA1-OPS-54	It shall be possible for the Operator to take manual control of the telescope, its subarrays, components and instrumentation.	Update of SKA1-SYS_REQ-2735.

6.6 Generation and calibration of science data products

6.6.1 Pipelines and data products

Science data products will be generated by the SDP in the science processing centres. There are several Level 1 requirements [AD1] for pipelines that will be available for the generation and calibration of basic science data products (e.g. images, spectral line cubes). These are:

Table 21: Level-1 requirements for basic imaging data products

ID (SKA1-SYS_REQ-####)	Description
2336	**Standard pipeline**. All pipelines will use the standard pipeline including the pipeline processing log and quality assessment log.
2338	**Calibration pipeline**. Will derive current telescope parameters using a recent observation and a Global Sky Model (GSM).
2339	**Continuum imaging pipeline**. Construct noise-limited wide-band images (including polarisation if requested) for observations up to 1000-hours integration time.
2341	**Spectral line emission pipeline.** Construct noise-limited channel cubes (up to 1000-hours integration) of spectral line emission with/without continuum subtraction.
2343	**Spectral line absorption pipeline.** Construct noise-limited channel cubes (up to 1000 hours integration) of spectral line absorption with continuum sources removed.
2345	**Slow transient pipeline.** Construct a continuum image, after a GSM has been subtracted for every interval in time, searching for transient sources and producing a time-ordered catalogue of those sources.

Associated with these pipelines are more specific requirements for generating what may be considered as advanced data products. These are:

Table 22: Level-1 requirements for advanced data products

ID (SKA1-SYS_REQ-####)	Description
2340	**Continuum imaging data products**. The first *n* moment images for multi-frequency synthesis, residual images, sensitivity image, representative PSF image.
2333	**Continuum source finding**. Conducted on images generated by the continuum imaging pipeline (#2339). To include polarisation if requested.
2342	**Spectral line emission data products**. To include spectral line cube images, continuum model images, sensitivity image, and representative PSF.
2344	**Spectral line absorption data products.** The same as for #2342 but for products generated by the spectral line absorption pipeline (#2343).
2334	**Spectral line source finding.** To be conducted on image cubes generated by the spectral line pipeline (#2341).
2335	**Stacking.** Spectral line stacking to be performed on image cubes generated by the pipelines using *a priori* known source lists.
2346	**Slow transient data products.** Catalogue of found sources, sensitivity images and representative PSF.

6.6.2 Calibration of data products

A draft calibration framework for SKA1 exists [RD3] that attempts to provide a unified view of the system calibration of all aspects of a SKA1 telescope. System calibration includes all aspects of the measurement process and not just those related to astronomical observations. Section 3.1 of [RD3] lists all of the Level-1 requirements as extracted from [AD1] and is not repeated here.

At the time of writing, the calibration strategy for SKA is still a work in progress and no further discussion will be presented in this document until that work is complete, and the consequent operational requirements are better understood.

6.7 Data flow

The question of how the large data volume that will be generated by the SKA will be reduced, curated and served to the community via Science Archives is one that, at the time of writing, is being reviewed by the Data Flow Advisory Panel. In what follows, the flow of information and data, and the consequent actions involved in going from a science proposal to data products, are described (see Figure 3).

The flow of information starts with the scientist writing and submitting a science proposal. This proposal includes all the technical details necessary to carry out the proposed observations (i.e. observing strategy, configuration of instrument(s) and telescope(s), calibration needs). The proposal is then reviewed and assessed and, if successful, the proposal becomes a project. At this point, it is possible to refine the observation design, following feedback from the time allocation committee, for instance. From this, the requisite numbers of schedule blocks are constructed. Schedule blocks from all projects are aggregated into a database and, together with the project rankings from the time allocation process, an observing plan is created on medium and short-term timescales (the length of each are TBD). Commensality between projects will be identified and implemented at this point (see §6.5.2). The ordering (i.e. priority) of projects within the plan could, in principle, also be informed by the project and/or national completion statistics. At the time of writing, the policy for this has not been determined.

Once constructed, the observing plan for each SKA telescope is replicated to the appropriate TM in AUS/RSA. TM then attempts to execute the schedule blocks in the order specified by the short-term plan. Local dish/station availability and short-term maintenance schedules inform TM whether any single schedule block can be feasibly executed (see §6.5). If not, then TM moves to the next item in the plan if it is the best alternative. This may require a re-optimisation of the short-term plan. As the SKA will be running a flexible queue to maximise its efficiency, each telescope will need to adapt its plan according to any events that are triggered during the observing period (e.g. ToO events, faults).

The length of the observing plans that are passed down to the telescopes is TBD. One possible operating model is to pass/mirror a mid-term plan (of say 2-3 months) to the local sites, and to regularly (e.g. weekly) update this with a short-term plan from GHQ as the completion statistics (and other influencing factors) are incremented. This allows for maximum redundancy, while reflecting current and/or changing priorities, in the case of unforeseen events that lead to loss of network connection between GHQ and the telescope sites.

Data obtained by the arrays are passed to the CSP for correlation, and non-imaging processing, and then to the SDP pipelines for processing into calibrated data products. Throughout, the systems are monitored for faults, and the quality of the data is examined.

Note that the data reduction pipelines are an integral part of the observing workflow. At other observatories it is normally an operational requirement that any failure of data reduction should not stop the acquisition of new data. For the SKA, this will not be possible as there is no capacity for reprocessing data. It is conceivable that if the SDP pipelines go down for any significant length of time, the data acquisition will also cease and some observations may need to be repeated.

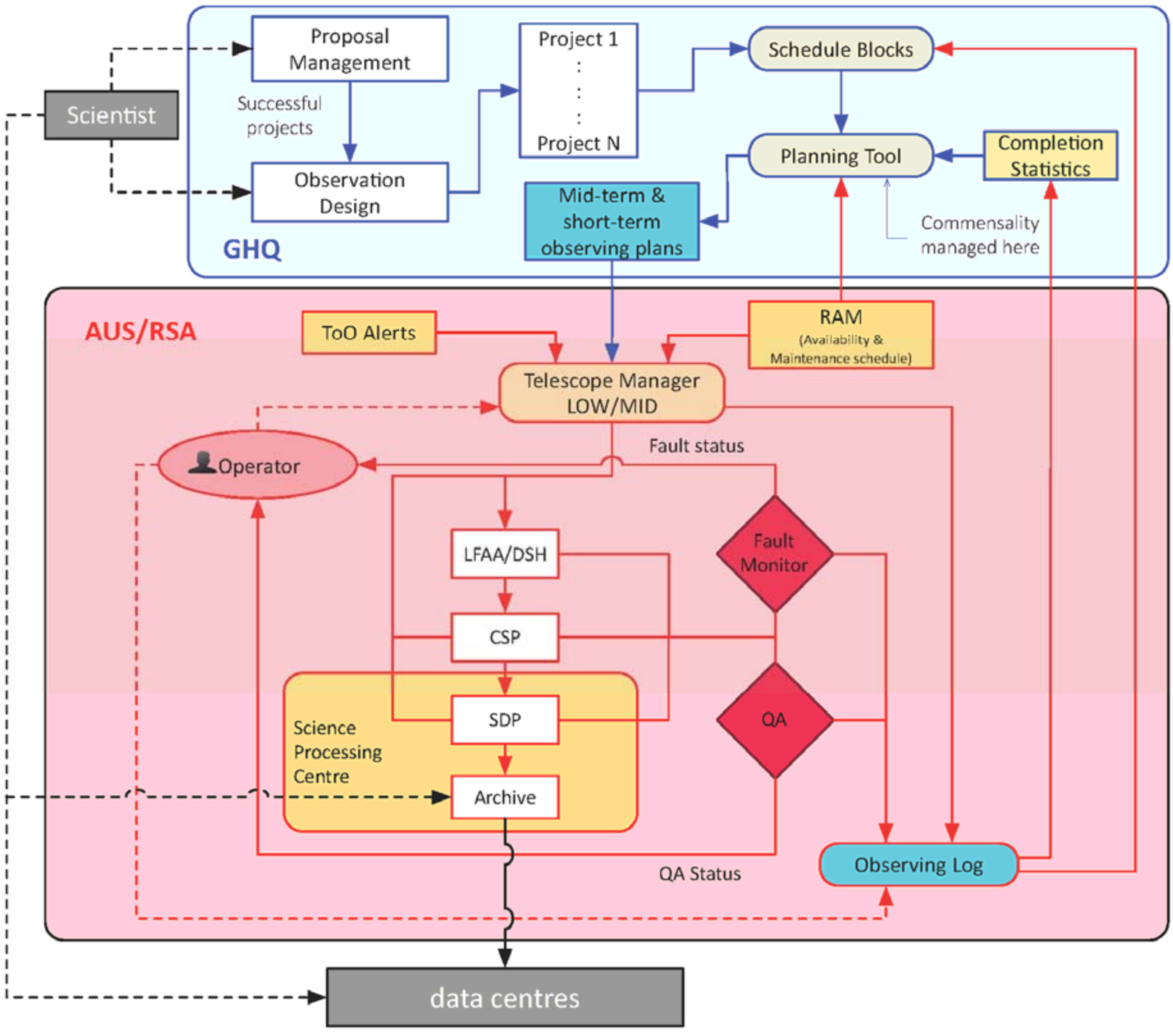

Figure 3: Flow of information (proposals and schedules), process (telescope manager, fault monitoring, QA and log), and data (observing and reduction). Dashed lines represent human interactions with computer interfaces.

At all times, the fault and Quality Assurance (QA) statuses are recorded in the observing log for each observation. Any action taken in response to these should also be recorded in the log. The specifics of QA are still TBD (e.g. whether there will be a standard set of QA metrics applicable to all projects, or whether they will be project specific, or both).

Table 23: Operational requirements (quality assurance)

No.	Requirement	Level 1 Status
SKA1-OPS-55	Quality Assurance (QA) from the pipelines will be reported to the Telescope Manager, enter the log and project database when appropriate.	New requirement.

The processed data, whether they pass basic and project-specific QA or not, enter the archive at the Science Processing Centres. If the data fail QA then the Operator is informed (with detail as to the specific observation and reason for the failure) and the observing/project log updated. The Operator may then decide whether to continue or repeat the schedule block (see §6.10.2).

Several requirements that pertain to science data products, pipelines and data archiving are contained within [AD1]. These are listed below.

Table 24: Level-1 requirements for pipeline and archive

ID (SKA1-SYS_REQ-####)	(Brief) Description
2821	**Archive**. There shall be an archive for each telescope. (see principle 21 in §3.2)
2348	**Role of Science Processing Centres**. To convert CSP output into science data products to be stored in the science data archive.
2350	**Mirror sites**. All data in science archives shall be mirrored offsite at a secure location.
2352	**Web interface**. The science data archives shall be accessible via a web interface.
2353	**Virtual Observatory Interface**. The science data archives shall be accessible to the VO.
2354	**Archive API**. Publish a user accessible API for the archive.
2357	**QA annotation**. Allow users to annotate their data with QA annotations.
2366	**Distribution of data products.** As limited by resource constraints, it will be possible to deliver science data products to approved off-site facilities.
2739	**Levels of access.** Allow anonymous access (with limited capabilities) or via SKA A&A.

Additional, new requirements are listed below.

Table 25: *Operational requirements (event logging)*

No.	Requirement	Level 1 Status
SKA1-OPS-56	There shall be an observing log, for each SKA telescope, which is automatically populated by the Telescope Manager as new Schedule Blocks are started.	New requirement.
SKA1-OPS-57	The Telescope Operator shall be able to amend and append to the log entry, at the scan level if necessary, any comments and quality flags, as well as time-stamped narrative comments.	New requirement.
SKA1-OPS-58	The log entries, QA reports and narrative associated with each observation will be appended to the project record on the database.	New requirement.
SKA1-OPS-59	Project and National completion statistics shall be tracked.	New requirement.

6.8 Data rights and publication

At the time of writing, the data access and publication policies for the SKA have not yet been formalised. It is expected that SKAO will own all SKA data, and PIs will be awarded access rights to the data products associated to their projects for a given proprietary period (TBD). A standard acknowledgement statement(s), for publications that include SKA observations, will need to be ratified by the SKA Board.

6.9 User Support

In the context of this section, SKA users are those scientists with access rights to either KSP data or PI data, and those scientists who access the publicly available data products via the science archive(s). We anticipate that such users will seek support, in the first instance, from Regional Science and Data Centres (RSDCs, which at the time of writing are not yet defined). This section describes those user support functions that will be provided by the Observatory to service requests from the RSDCs or from individual users.

The specific responsibilities that Observatory operations staff will have to SKA users are outlined in Figure 4. This requires setting up a SKA Help Desk facility through which SKA users will be able to post requests for support on specific issues, report software bugs, problems or faults, make general enquiries or provide feedback to the observatory. The SKA Help Desk will generate a ticket and reference number for any enquiry. It will be possible to assign a specific member of staff responsibility for that ticket.

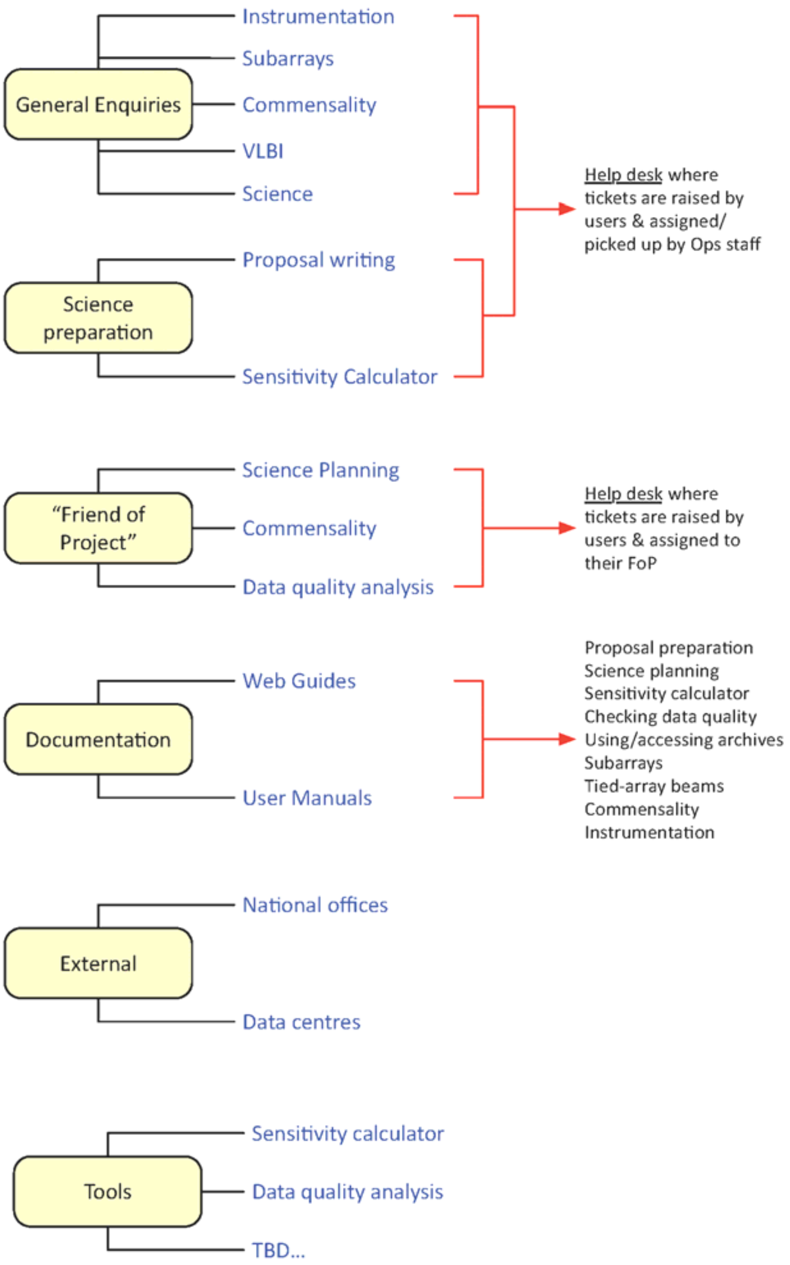

Figure 4: User support and responsibilities.

Operations support staff will be assigned to each approved project as a "Friend of Project" (FoP). The FoPs will serve as points of contact for users, raising specific queries about their project planning and data quality (i.e. FoP status persists after data are collected on a project). Queries that generate tickets via the Help Desk system should assign that ticket to the FoP automatically.

Table 26: *Operational requirements (Help Desk)*

No.	Requirement	Level 1 Status
SKA1-OPS-60	There shall be a SKA Help Desk system to allow queries to be raised and problems/faults/bugs reported. The Help Desk system will generate tickets that shall be assigned to a SKA staff member.	New requirement.
SKA1-OPS-61	Operations support staff shall be assigned as “Friends of Project” to specific projects. Any queries raised by a PI on their project will be automatically logged and assigned to the FoP by the Help Desk system.	New requirement.

It is anticipated that some fraction (TBD) of the user support function will be located in member countries and resourced separately from the SKA Observatory. The SKA office will have to service those users, either directly (GHQ) or via national offices and data centres.

As part of user support, SKA Operations will be responsible for maintaining and providing documentation for all aspects of SKA functionality that SKA users will either need to interact with or have knowledge of. This documentation shall be in the form of (downloadable) PDFs, and web-based guides, FAQs, and how-tos (see Figure 4).

6.10 Operational performance

6.10.1 Fault rate and observing efficiency

Raw metrics of operational performance are the fault rate and the observing efficiency. The fault rate is the amount of observing time that is lost to faults compared to the observing time available for science (as defined by the Science Availability in [RD4]).

Observing efficiency is a measure of how much of the available time, excluding faults, is spent doing things other than science observing. This can be calibrations, instrument setup, slewing and target acquisition.

6.10.2 Fault reporting

The logging of faults detected by the system shall occur automatically and the nature of the fault automatically described in the log from the error condition and/or fault code. 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 Telescope Operator will be automatically notified 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).

If a fault is detected, the Operator will decide whether to,

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

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

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 accessed if the fault or its solution is not familiar to the Operator.
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 instance, if a single dish 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 the dishes in the subarray.
    - QA alerts should inform the Operator whether there is any significant degradation to the data compared to expectations.
5. Continue observing if possible.
    - If it is not possible to continue with the present observation, then the next feasible observation in the plan should be observed. In most cases, this will occur automatically.
    - The telescope status will be updated automatically once a serious fault is realised so that TM can flexibly and dynamically change the short-term plan to choose the next best available and feasible schedule block to execute utilising the available resources.
6. Annotate the fault report with information that should contain:
    - a narrative describing the fault, its characteristics and the impact to observations not already described by the automated report;
    - any corrective actions taken, and;
    - the amount of observing time lost, if any.
7. Notify appropriate personnel of the faults.
    - In the case of a severe (i.e. time-losing) fault, the telescope Operator should attempt to notify the appropriate personnel, if feasible.
    - Operations support staff should be regularly monitoring the logs and reports from the telescopes, and identifying any issues that need to be accelerated.
    - It is the telescope Operator's responsibility is to provide a clear and concise fault report that will allow the local operations support staff to respond in a timely manner.

Table 27: *Operational requirements (status reporting)*

No.	Requirement	Level 1 Status
SKA1-OPS-62	The operational state of each SKA telescope, and its subsystems, shall be logged at all times.	New requirement.
SKA1-OPS-63	There shall be fault monitoring to capture alarms and report them, in human readable form, to the Telescope Operator.	New requirement.
SKA1-OPS-64	There shall be a searchable SKA fault database where new, open and closed faults will be recorded and archived for future and continual reference.	New requirement.
SKA1-OPS-65	The fault codes shall be linked and traceable to the repair/corrective actions in the fault database.	New requirement.

6.11 Time accounting

The elapsed time to observe schedule blocks (i.e. time to slew and/or acquire an object, etc.) for particular projects shall be tracked by TM and then subtracted from the time that has been allocated to that project. TM will also have to account for the total elapsed time, and the Telescope Operator will be responsible for ensuring that the elapsed time recorded tallies with the actual time available (e.g. 24 hours). The time will be accounted for against various categories (see §6.2.1). These times will be recorded in the log, and reported in the observing report filed at the end of an observing period.

At the end of each observing period (TBD, but at least once per 24 hours) TM shall generate and store an observing report that is automatically emailed to operations staff for review. This report should contain a log of all observations carried out, 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). The Telescope Operator will ensure that the total time reported tallies with the total available time (e.g 24 hours for a daily report).

Table 28: *Operational requirements (time accounting and reporting)*

No.	Requirement	Level 1 Status
SKA1-OPS-66	The Telescope Manager shall track the elapsed time spent observing projects and deduct this from the time allocated to the projects.	New requirement.
SKA1-OPS-67	The Telescope Manager will account for the elapsed time at the telescopes against several categories.	New requirement. (see SKA1-OPS-06)
SKA1-OPS-68	At least once every 24 hours, the Telescope Manager shall generate a report of the observations carried out, plus any other events, for each telescope. This report will be automatically made available to Operations staff for review.	New requirement.

6.12 Operational performance monitoring

The metrics that will be used to measure the operational and scientific performance, competitiveness and impact of the SKA are described in §4. The operational requirements to track these metrics are covered elsewhere in this section. In summary:

- System downtime due to faults – tracked through the observing logs and fault database (see §6.10), as well as the time accounting system (see §6.11).
- Operational availability
- Observing efficiency – tracked through the observing logs and time accounting system by comparing the time spent on science observing and/or calibrations to the total time available for science.
- Project completion – tracked through observing logs and the Project Portal (see §6.4).
- Ratio of processing to observing time – tracked through the computing and observing logs providing a measure of the efficient use of the computing facilities (this ratio should ideally be close to 1).

7 Engineering Operations

7.1 Availability

Engineering Operations comprises those activities necessary for the maintenance and development of the telescopes and the SKA infrastructure in the host countries.

The scientific success of the SKA, as described in §4 above, requires that the telescopes be available for science observations for as much of the time as possible within the constraint of available resources. A top-level description of availability is provided in [RD1] and relevant definitions are given in Table 29.

Table 29: *Availability definitions*

Term	Description
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.[7]
Availability	Availability is the probability that a system is operating satisfactorily 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	Inherent availability is 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.
Operational Availability	Operational availability is 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 some time after the failure has occurred. It is thus a measure of not only reliability and maintainability, but also of the response time of the support system.

Engineering analysis indicates that the SKA telescopes should offer an inherent availability of >95%. From the perspective of observatory operations, however, operational availability is the relevant figure of merit.

Table 30: *Operational requirements (availability)*

No.	Requirement	Level 1 Status
SKA1-OPS-69	Each SKA1 telescope shall have an operational availability of at least 95%.	Revision of SKA1-SYS_REQ-2716.

[7] This definition 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.

Achieving this ambitious level of operational availability requires:

a) that all telescope systems (including both hardware and software) be designed for reliability and maintainability commensurate with this requirement. Allocation of availability to telescope elements is in [RD4]; and
b) that the support system be designed to provide a response time commensurate with this requirement. The Support Concept is described in [RD5].

In addition, the scale of the SKA demands an industrial level of logistics engineering: the Integrated Logistics Support Plan is at [RD6].

The definition and requirement 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 calendar year.

7.2 Constraints

The constraints in §5 will apply to Engineering Operations. Of particular importance are:

- rigorous implementation of the Safety, Health and Environment standard for all activities on the remote sites; and
- protection of the radio-quiet environments of the remote sites.

These constraints lead directly to a desire to minimise the human footprint on the two sites. This is not formulated here as a requirement, since the on-site staffing will be driven by maintenance demands to meet the availability requirement; rather, it is noted here as a desirable outcome.

The design of the SKA incorporates stations (LOW) and dishes (MID), and their associated infrastructure (power and signal), at large distances from the array centres. Moreover, the Telescope Operator may be in a location remote from the array. It is therefore essential that all on-site systems be engineered to fail to a safe state in the event of loss of power or communications.

Table 31: *Operational requirements (fail-safe)*

No.	Requirement	Level 1 Status
SKA1-OPS-70	All telescope systems shall be designed to fail to a safe state in the event of loss of power or communications.	Revision of SKA1-SYS_REQ-2525.

7.3 Standards

The SKA is being designed by multiple, world-wide consortia. This distributed structure raises the risk of multiple systems being employed in the design by different groups, selected according to their own design criteria, to perform identical functions. Such diversity of systems inevitably increases the support requirements and the operational cost. In general terms, in the absence of compelling reasons to do otherwise, common standards should be employed to the maximum possible extent. Such standards will be approved for implementation by the SKA Office and will be specified in the Level-1 requirements.

Table 32: *Operational requirements (standards)*

No.	Requirement	Level 1 Status
SKA1-OPS-71	Common standards shall be employed in the design of SKA1 to the maximum possible extent. Requirements on current standards are given explicitly in [AD1], and will be updated as needs arise.	New requirement.

7.4 Acceptance

For both telescopes, components will be handed over from the construction project to observatory operations incrementally in a series of roll-outs. Each handover will involve an acceptance review, in which compliance with the operational requirements will be assessed. Although a full set of acceptance criteria has not yet been developed, a documentation set covering maintenance requirements will certainly be included.

7.5 Maintenance Strategy

A detailed maintenance plan, encompassing both hardware and software components, will be developed as part of the system design. In this section, some general considerations are presented, leading to some top-level requirements.

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. 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, and obtaining the appropriate balance will be an evolutionary process requiring constant vigilance.

It is anticipated that the maintenance plan will contain both preventive maintenance and corrective maintenance, varying from system to system, depending on the known failure modes. The strategy will be informed by a standard Failure Modes, Effects and Criticality Analysis of each telescope system.

Repair work in the field will be minimised. All on-site telescope systems must be 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 return the faulty unit for repair or replacement off site. An inventory of working spares must be maintained.

In order to minimise the number of staff on site, a remote diagnostic capability is essential. The monitor and control systems should permit deep interrogation of sensor values, and should enable remote identification of faults down to LRU level so that maintenance and repair activities can be planned in advance and carried out efficiently.

Given the extreme 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. 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 the entire telescope out of service for a period. Further details are provided in the Support Concept [RD5].

Table 33: *Operational requirements (maintenance)*

No.	Requirement	Level 1 Status
SKA1-OPS-72	A remote diagnostic capability shall be provided to enable remote identification of faults down to LRU level.	New requirement. (SKA1-SYS_REQ-2544 refers to self-test capability but does not specify remote access to this information)
SKA1-OPS-73	All on-site telescope systems shall be designed to make maximal use of LRUs.	New requirement.