DSA-2000 Document No. 00003

Concept of Operations

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Abstract

DSA-2000 will be an array of considerable scale and complexity, representing a large leap forward in next-generation radio telescope instrumentation. Given this, the requirements associated with the operations, maintenance, site infrastructure and general management of the array are similarly distinct from previous and current operational facilities worldwide. This document captures and describes the concept of operations envisaged for DSA-2000 based on these requirements,

# Introduction

In this document, we outline the current concepts related to how the DSA-2000 array will operate and be maintained. With 2048 antennas spread over a 19 km x 15 km area, the operations concept needs to be well thought out to maximize efficiency and minimize staffing requirements.

At this initial stage, we also identify key assumptions or questions that will need to be verified or determined before a full model of operations can be developed and adopted.

# Array Operations Concept

The DSA-2000 project is primarily focused on carrying out pre-planned science surveys. The only planned departure from routine observations and maintenance would be for Targets of Opportunity (ToO) and Director’s Discretionary Time (DDT). A critical part of the system will be the development of smart automated scheduler and a monitor and control system that are both designed to require minimal human intervention.

In general, once the array is commissioned, it will be continuously observing – performing the cadenced survey. Maintenance and repairs will be carried out during observations, usually affecting a small fraction of the capabilities. Exceptions to this may occur, for example if a major single point failure occurs, such as the failure of the site uninterruptable power supply (UPS). As much as is possible, single-point failures will have mitigation plans, for example by way of redundant hot and/or cold spares. For failures that affect part of the system, modular line-replaceable units (LRU) will allow quick recovery. LRUs will be either hot-swappable or able to be powered down without affecting any other part of the system.

On-site staff will perform maintenance tasks daily during the week, while at least one person off site will be assigned to monitor the performance of the system and coordinate on-site daily tasks, including scheduling repairs that are not part of the routine maintenance task list.

The science requirements call for 97% of the collecting area and 65% of the total band to be available more than 80% of the time. Conversely, the array is deemed to be fully available with 97% of the collecting area and 65% of the band capable of being processed through the entire system. The collecting area/bandwidth availability can be extended to other subsystem, for example, failure of an RCF node will remove one antenna, while failure of an RCP node will remove part of the band. More complex failure trees will be developed during the Final Design Phase to refine the availability model.

## Automated Scheduling

DSA-2000 will focus on conducting large-scale surveys of the sky for 65% of its on-sky time, alongside other survey components including pulsar surveys and reactive time-critical observations. Given the fixed nature of much of this observing, an automated scheduling system will be adopted in order to maximize the efficiency of the array. As well as handling the main survey observations, the scheduler will also need to account for planned and unplanned interruptions such as maintenance and ToO/DDT observations.

The intent is for this automated scheduler to be robust, autonomous, dynamic, reactive, deterministic, communicative and transparent, as defined below:

* **Robust:** able to be trusted with reliably and effectively making appropriate scheduling decisions that are comparable to the decision-making processes of equivalent human operators
* **Autonomous**: capable of making decisions without direct human input in the majority of cases, unless human oversight or collaboration is required (e.g. in the case of safety of the system)
* **Dynamic**: designed to make decisions about what to observe next based on its understanding of the current environmental conditions, live system constraints, content of the observation pool, required sky/field constraints and a series of weightings which determine priority
* **Reactive**: able to react to changing conditions (e.g. weather, hardware failure, etc) and change course in an appropriate way at all hours of the day to maximize science output and data quality
* **Deterministic**: given the same initial conditions and system status, the scheduler will make the same decision in each case, ensuring decisions are explicable and predictable given constraints
* **Communicative**: notifies relevant people as appropriate as part of standard operational workflows or in the case of issues requiring human attention or expertise in order to resolve
* **Transparent:** via appropriate interfaces, the decisions made by the scheduler are logged and able to be understood by human experts, who in the ideal case can contribute to improving or adjusting the decision-making process of the scheduler as required

It is expected that there will be a base level of scheduling control which involves submitting a parameter set of variables that specify the system setup for a given observation, including parameters such as the frequency setup, field coordinates, constraints, etc. This low-level scheduling control will be communicated with by the autonomous scheduler, but can also be interfaced with by other means of controlling the system (e.g. more manual specification of observations). This enables flexibility in telescope control, which will be required particularly early on during commissioning or in cases where a particular mode of operation has not yet been integrated into the autonomous scheduler.

An overall architecture for the scheduler will be prepared prior to the start of construction, capturing the flow of operations that the scheduler will follow as well as outlining the expected features and modules it will need to contain. This design will be flexible as much as possible to ensure that future identified requirements can be incorporated into the scheduler over time, given the high likelihood that commissioning may shift any assumptions made prior to live operations of the system. The overall control of the system will be an evolving process from highly manual (in the very early stages of commissioning) to semi-automated (human control in collaboration with the improving scheduler) to fully autonomous (where the scheduler is primarily responsible for operating the system).

### Sky coverage and tiling

DSA-2000 will primarily spend its time mapping the visible sky. The field list covering the sky is expected to be ~8700 pointings which are grouped into a tiered hierarchy determining which fields will be mosaicked together at the processing stage. It is anticipated that fields will be treated individually during the scheduling decision-making process, with a prioritization scheme in place to greatly increase the priority of fields that are located within the same tile or neighboring tiles which share edges, but an approach where tiles are instead scheduled (including scans of their associated fields) will also be considered. Each tile is currently planned to be roughly 5 x 5 deg in size, with ~25 fields within a given tile, taking an estimated ~5 hr to be completely observed.

### Array safety considerations

The automated scheduler will act essentially as a proxy for a human operator, and thus will (as much as possible) not take direct responsibility for the safety of the array or associated hardware. Instead, safety controls will be in place at several layers: e.g. local control which overrides remote control (for example, in the case of local antenna maintenance), hardware controls/limits which oversee safety of equipment directly, software controls/limits which provide a back-up measure of safety and finally the scheduler, which will be able to access an overview of the current system and environmental status to aid with making decisions regarding scheduling.

As such, the primary control for safety will sit with the domain of monitoring and control, and the scheduler will act as a secondary control/back-up. For example: in the case of strong winds or bad weather, the array should automatically stow based on system-level thresholds and alerts, but these alerts should also be visible to the scheduler which then can access them and choose not to attempt scheduling until the alerts have returned to normal. In the case of the scheduler attempting to schedule, the system would intervene/override and error any attempted observations to preserve the safety of the array.

Another example would be limiting power usage in winter (especially at night), given that the array is expected to rely heavily on solar power. The scheduler can be made aware of this logic via control system variables and alerts (e.g., “power-saving mode active”), but should not be primarily responsible for the actions that need to be taken on the hardware side to preserve the safety of the array. The scheduler *can* be made aware of how its decision-making process should change given this state (if that is a factor to consider) but would only be reacting to such a power-saving mode rather than controlling it directly.

A final example would be managing slew/wrap limits and slew speeds, which is a case again where primary decision-making control should be in the telescope control system at the drives level. The scheduler can be designed to consider estimated slew speeds as well as logic around avoiding hitting wrap limits unnecessarily, and make decisions accordingly, but it should not be responsible for directly controlling the way that the drives respond to a given position request. Instead, the scheduler will be responsible for generating a parameter set including the requested position, which the telescope control system will accept and slew to. We expect any low-level drive functions such as unwrapping will similarly be automatically handled as part of monitoring and control rather than on the scheduler side.

### Management of survey progress

At the lowest level, each attempted observation will be tracked in a database that can be accessed via the command line. This database will contain information about the specification parameters, variables associated with the attempted observation (if it starts), logs of the progress of the observation and other information as relevant. There will also be a visual web-based interface to this database that is designed to offer quick and comprehensive insight to what has been observed (or attempted to be observed) on the array. This web-based interface should be designed to be readily accessible to a wide range of relevant human experts (including science PIs) who will need to have oversight over survey progress and status; and should work on a range of devices (e.g., laptops, tablets, phones) to ensure distributed oversight of the survey progress is possible and straightforward. This visual interface does not need to give control of the array (since that will be primarily handled by the automated scheduler), but instead will allow the relevant human experts to track and oversee what is happening.

Ideally, the web-based platform will offer other useful functionality as required. One example would be to aid with transparency of the scheduler decision-making process (for relevant staff) by showing logs, current variables and states associated with the scheduler and potentially offering ways for human experts to adjust or adapt the decision-making process if needed. Another example would be for statistical and visual assessment of the observations – e.g., being able to view/calculate success rate and efficiency over a given period for reporting, or interactively view the portion of the sky covered for a given period. It will be important in designing this platform that 1) relevant parties likely to use it are consulted for possible use cases, and 2) that it is designed in a way that allows it to be extended readily in future to cover use cases that are inevitably missed at the time of initial design.

### Simulation plans

The scheduler will be designed to have at least two simulation modes: 1) when run manually by a human in “current status” simulation mode, it will run through its logic processes and report on what it would choose to do next given the current state of the system (either at the current time or at an arbitrary time specified), and 2) it can be run in a simulation mode with a specified set of initial conditions (and probabilistic error rates or interruptions), an observing pool and a time range and will report on what it would choose to do over that given time period. These simulation modes will support the exploration and investigation of the decision-making process employed by the scheduler based on its existing logic, and also enable human experts to test and analyze the impact of possible changes to that logic. In the absence of the full automated scheduler, more basic and fundamental simulations will be carried out in the lead-up to array construction that will inform the future development of both the scheduler and the eventual proper simulation modes.

## Human involvement in operations

The modern era is one where computing and automation have advanced considerably, such that systems which traditionally involved high levels of human oversight can be transitioned to ones requiring more specific and targeted human input. Operations of complex systems such as telescopes is one such example, where the data has become increasingly multi-dimensional and of such large scale that it makes increasingly less sense for human operators to sit at the centre of monitoring and control.

In the case of DSA-2000, there are several elements which suggest the necessity of low dependency on consistent human effort:

* Remoteness: the system will be overseen at a distance, with minimal or no staff on site to watch either the telescope or the environment closely
* Distributed team: staff involved in DSA-2000 operations will be minimally split between several sites, including OVRO, Pasadena and (potentially) near DSA-2000 itself
* Survey focus: the goal of conducting surveys at high efficiency requires reducing the number of places where human reactions or interventions can create bottlenecks
* Scale: with 2000 antennas and a complex backend associated with each of them, the number of monitoring points relevant to decision making about operations will be in the millions (at least)
* Low-cost budget: the project is aiming to build an array of ambitious scale while being cost-efficient in terms of budget, and this will require minimizing the reliance on human resources

With the intention of thus maximizing the operational throughput while minimizing the costs to the project, the use of designated human operators in the traditional sense is not seen as a necessary part of the operational workflow. What will be necessary is having appropriate automated monitoring and control in place (potentially involving AI and designed with a collaborative intelligence model in mind) such that the relevant human expertise can be provided at points where it is necessary.

It will likely be beneficial to have a designated operations team in place, but with the right amount of automation alongside a small fraction of distributed development/software support, this team can be relatively small. As a minimal example, this team could consist of:

1. Science operations lead (from specification to raw data production)
2. Data operations lead (processing of the raw data)
3. Archive operations (storing and transferring the processed data).

A fraction of operational support would be required from domain experts in the relevant parts of the DSA-2000 system (e.g., covering support for issues with antennas, receivers, digital backends, etc). This should be allocated as part of the ongoing roles for those who have the relevant expertise in these systems (e.g., at the 10-20% level, adjusted based on what is required but ideally kept at a low consistent level).

It is noted that student involvement and training is expected to be part of the overall commissioning and operations of DSA-2000, and this can be factored into the plan for how the autonomous scheduler interacts with relevant human experts. For example, students could be rostered on as general contact points as part of standard operations (e.g., the first point of contact if something urgent needs to be brought to attention) and trained in both how the automated system works at a high level, as well as how best to react if something is alerted to them. For this model to work, there should be dedicated effort into designing this such that the value both provided by the students and for the students is maximised (to ensure engagement and investment in the role that they would be acting in).

## Data Quality Assurance

The combination of multidimensional complexity, automation and real-time workflows in DSA-2000 necessitates comprehensive and reliable data quality assurance approaches. Specifically, it will be important to be able to isolate issues and adjust the system quickly in the case of poor quality to minimize the impact on recorded data, connecting monitoring data from hardware, software, raw data and processed data. Many of the subtleties of data quality for DSA-2000 will become most apparent during the commissioning and early science phase, when the array is established enough to produce data at a scale and of the quality expected during full survey operations.

The planned approach for data quality is two-fold: 1) preventative data quality assurance in the form of (mostly unsupervised) anomaly detection, and 2) reactive data quality assurance that is based on lived experience with the array as it evolves towards full survey operations.

### Preventative data quality assurance

This will primarily take the form of anomaly detection, using unsupervised (or semi-unsupervised) machine learning on available data – both telescope monitoring data and data products. Based on experience with similar telescope arrays (e.g., ASKAP, Apertif), we expect that raw data autocorrelations will provide a useful insight into the state of each antenna and enable identification of systematic issues affecting a given antenna, subset of a given antenna, digital system (e.g., correlator) or environment. This form of anomaly/outlier detection can be prepared early in the commissioning process and further developed during commissioning but will be most effective when the array is able to (mostly reliably) produce consistent data.

### Reactive data quality assurance

The reactive forms of data quality assurance will be developed as part of the commissioning process, based on learnings from the telescope data while it is handled and assessed closely. We expect this form of data quality assurance to be largely driven by human insight and expertise, making links between components of the system that more directly identify issues or problems with the array (compared with the more generic assessment to be provided by anomaly detection).

### Links with Collaborative Intelligence

Alongside trends of increasing machine learning and artificial intelligence are parallel discussions about Collaborative Intelligence (CINTEL), which specifically focus on the most effective ways that humans and machines can collaborate with an emphasis on identifying the unique areas where human expertise and insight is most valuable. This topic will be highly relevant to DSA-2000 which - to efficiently survey the sky - will need to be as automated as possible with high efficiency and reliable data quality. As such, we expect an allocation within the DSA-2000 team to be focused on designing, implementing and improving the data quality assurance workflows such that the reliance on human intervention or judgement is minimized while the data quality output is maximized.

## Software and Service Management

Software is used to operate the telescope, the real-time processing, and communicate its state to users. Services are persistent processes that run software to facilitate communication between subsystems or between automated and human actors. Since software is updated often and depends on other software, we must carefully plan for its management and continual updates.

### Software management

We will use the version control system git to track development progress, associate performance to code changes and release code. Groups may develop in the same software repository by creating branches for new features. After unit testing and review, these changes are merged and made available to other developers of the same repository.

The complexity of software and the number of distributed developers motivates a continuous integration and testing system. We will use this concept to prevent (or restrict) small errors in software from cascading into systemwide failures. At the lowest level, we will use unit test frameworks that are available in most software languages (e.g., “pytest” for Python). New feature code should pass the most common style check tool in their language (e.g., PEP8 for Python and gofmt for Go). Automated linting of code should be encouraged by integrating it with automated testing frameworks.

Code reviews will be performed to ensure consistency with style requirements and minimal coding standards. Reviews will also ensure changes are consistent with feature requests backed by requirements or bug reports. The goal here is to control code creep and maintain a consistent architecture and standards.

After features are unit tested and reviewed, they can be merged into the main branch for integration testing with other software repositories. This will happen in dedicated hardware that includes other software from the same subsystem (e.g., monitor and control interfaces to the post-processing system). Teams will have a fixed schedule for testing the deployed software (e.g., every Wednesday). This builds confidence in the live system and helps developers plan to deploy new features. Deployable versions of all software packages should be uniquely tagged both in source code repositories, as well as in all deployable artifacts. A record of versions of all software packages deployed in production will be maintained. Ideally, a versioned, complete software bill of materials for every deployed package will be maintained as part of the deployment record to support reproducibility.

Software issues and development will be managed with a ticketing or issue management system. Tickets are assigned to define new features or issues. These tickets can be grouped into milestones to develop new capabilities. These milestones can drive planning through “agile”, “scrum”, or other software development practices.

### Service management

Services are the software analog of a hardware component. They are designed to be highly available resources that perform basic tasks. Users of services may be either automated or human actors. An example of a service is a tool that accumulates logs from software systems and makes errors discoverable by operators.

As services are made of software, they must be tested as any software component. Beyond testing, they need to be monitored and controlled, just as hardware components are.

We will develop services based on experience with operations, both on arrays built before DSA-2000 and the array itself. The commissioning phase will refine the service requirements and iterate on their design. As institutional knowledge grows, the operations will transition from in-person or scripted operation of services to automated, discoverable, monitored services.

The design of the services should support both manual and automated operations from the beginning. This requires a hierarchy that separates “low” concerns from “high” concerns. Automation is done by building tools that have visibility and understanding of low concerns, but can abstract them into high concerns. An example of this is a service to determine the quality data coming from an antenna; there are many complex inputs into this determination, but ultimately a service should decide whether the antenna is good enough to use (yes or no).

## Data Management

“Data” can refer to the science products made by the telescope, metadata that helps understand the state of the data (especially its value), and configuration information that defines how the system should operate. All these kinds of data need to be managed carefully to meet our goals of providing scientific utility for most of the operational lifetime of the DSA-2000.

### Radio Camera Processor data management

Data products created by the radio camera processor sub-system are delivered in real time to the data management sub-system and are not managed by the radio camera processor sub-system after their production. These data products are written to files on one or more file systems that are also available to the data management sub-system machines. The qualities of these data products indicative of their availability (*e.g.,* error correction, redundancy, failure modes) are solely a function of the file systems on which the files are written.

### On-Site data management

The array will produce science quality data at a high rate that is written to an on-site archive. This on-site archive will function as the primary source of the bulk of the data generated by the array. An on-site and off-site backup will be created at the same time and reflect the same state of the on-site storage system. The off-site copy will be physically delivered to a safe location (TBD) every four months.

The on-site data storage system will be backed up by a high-density storage device (e.g., tape drives) and physically moved off site. The goals of the backup are to allow restoration of the core science products in the event of a major problem. Examples include (1) a major disaster such as a fire or hacking of the control building and (2) accidental deletion of significant data in the on-site archive. Securing against these scenarios requires two copies be made: one stored on site to allow relatively easy restoration of data and one stored off site for maximum safety with less convenience.

### Off-Site data management

An all-sky mosaic of continuum image data will be sent to IPAC for processing and serving to the public. We currently assume that the site will have a fiber connection to a nearby town with high capacity to the internet via a commercial service provider. Transfer from site to IPAC must be done slowly, due to limitations on use of IPAC bandwidth. If that limit is too slow, then disks can be shipped from site to IPAC on a similar cadence as the off-site data backup.

At IPAC, the public archive will be shared via an architecture that is compatible with both on-premises and cloud-based deployment, since the economics and performance considerations may change over the lifetime of the DSA-2000 project. The data services will be designed to be compatible with both Posix-like filesystems and cloud-style object stores as storage backends.

Multiple off-site archives will be supported and integrated with a single DSA-2000 data portal managed by IPAC. This is done via data-discovery and metadata services existing IVOA standards. Users at one site may query for the existence of data at other sites and either access it, perhaps in limited quantities, remotely, or navigate to the archive interface and computing resources of the appropriate site.

### Configuration Management

Configuration management covers the hardware and software configuration of the telescope. Hardware configuration management is supported by the delivery of an Operational Support Baseline (OSBL), containing all the design and as-built documentation. The OSBL will be maintained and updated throughout the lifetime of the telescope.

The primary aim of software configuration management is always to manage reproducible, deployed software configurations, although this goal can be challenging given the methods and varieties of software configuration in practice. All deployable software packages, as well as sets of configuration parameters should be associated with version numbers to facilitate configuration management. It is likely that software packages and configuration parameter sets that are consistent with some subset of package versions will be directly managed by staff during testing and commissioning. Ideally the tools used by staff in testing and commissioning will also be used to ensure that system-wide configurations are reproducible and deployable with minimal effort by an array operator, but this capability itself will require development effort.

## Security

Security is site dependent, and the preliminary provisions will be adjusted as the confidence of permitting approval increases during the Final Design Phase. There may be a need for security considerations as there could be a concern about theft/vandalism. Provision has been made for 24/7 security presence on-site. Access control will be in place for buildings, including a dual layer access control for the data center. Security can be augmented by cameras. The final security situation will be evaluated with input from the local community and the Bureau of Land Management; and presented at the Final Design Review, based on a confirmed location.

### Cybersecurity

The existing cybersecurity plan is found in the Project Execution Plan. We are looking into bringing in consultants or support to help further refine and implement the plan. This includes the NSF Cybersecurity Center of Excellence, Trusted CI and have worked with various observatories. https://www.trustedci.org/ or [Woodstar Labs.](https://woodstarlabs.org/services/)

# Array Maintenance Concept

Array availability requires that at any given point, at least 97% of the antennas should be online and available for science use. It follows then that no more than 60 antennas should be offline undergoing preventative or reactive maintenance at any given time, but this would be the worst-case scenario and it would of course be better if the instantaneous number of antennas offline were significantly less than that. From initial installation of an antenna, it will be incorporated into the array until either 1) the antenna or a component fails, in which case it will be taken offline for preventative maintenance, or 2) it reaches the two-year maintenance threshold and then all components at risk of failing are replaced. Hands-on maintenance will generally be designed to be completed by teams of two people and will incorporate usage of Utility Terrain Vehicles (UTV) to minimize the need for dedicated new roads across the array, which would be additional environmental disturbance. Unplanned hands-on maintenance will be preceded by remote diagnostics, using sub-arrays. This creates the requirement for sub-arrays, even though there is no science case for it.

### Installation and tracking of antennas

Each antenna and its components when installed will be tracked in an accessible database, which will note the associated dates/ages and maintenance records of each part of the antenna. This will be used to track the age of components in the case of expiration dates for module replacement as well as for tracking the history of repairs or faults associated with each antenna.

### Determination of MTBF and MTTR

Mean time between failure (MTBF) and mean time to repair (MTTR) for DSA-2000 antennas will be determined based on experience during construction and prototyping as well as during commissioning, alongside predictions based on antenna design. MTBF should not significantly burden the requirement for antenna maintenance and MTTR should be minimized. Other important elements to determine as part of the commissioning phase will be the mean time it takes to travel to each antenna safely (and how this varies depending on the location of the antenna) as well as the mean time to service different potential failures. As the array ramps up towards full survey operations, these data will be in turn used to refine the scale of maintenance staff required when DSA-2000 is nominally operational.

### Operational impact of antennas under maintenance

Given that a fraction of the array will be offline at any given point, the operational systems will need to be designed to support and handle this system state. This means that each antenna (or group of antennas) will need to be able to be isolated from the system, e.g., put in a local state, both soft local (via software) and hard local (e.g., at the antenna, for safety). Reintegrating antennas on a regular basis will be a standard part of operations, which means handling the calibration state of antennas will be important. Recalibration and reintegration into the array shall be supported by the relevant subsystems. Reintegration processes can be scheduled to minimize impact on the operational array.

The engineering and maintenance tasks, which will be on-going while the array is operational, necessitates that the array is capable of operating with sub-arrays, even if there is no scientific requirement for it. Antennas taken out of the array can be operated individually or in groups as a sub-array to enable testing and development. All subsystems will need to be sub-array capable, or at least, sub-array aware. Up to 4 sub-arrays could be operational at one time, given multiple maintenance teams. Apart from the main array, the sub-arrays do not require fully automated operation.

### ML/AI for planning and scheduling maintenance

As noted in [Section 2.3](#_Data_Quality_Assurance), the use of ML/AI techniques will be adopted where suitable to ensure high data quality and efficient throughput. We expect the maintenance database to incorporate at least basic intelligence on this front to track the history of antennas and identify when particular antennas are approaching their maintenance windows. The degree to which AI might be used to plan and schedule maintenance is an open opportunity, in the sense that it should minimally be able to provide simple data on which antennas need to be dealt with in the near term, but in the ideal case could take into account e.g. antenna location, staff rosters, existing scheduled maintenance and provide an optimized plan for carrying out the maintenance itself. It would similarly be an optimal outcome if the maintenance database were linked in a meaningful way to monitoring data, such that identifying preventative maintenance paths could be a possible option if desired (though it would depend on the cost-benefit of this kind of approach, as it may be simpler to just reactively replace where necessary or aim to reach the two-year window).

### Logistics support

The scale of the DSA-2000 is a large step up from traditional radio astronomy instruments. Support must be streamlined in order not to cause excessive operational cost. The system will be supported with a model that draws from the military, with the following levels corresponding to the O-I-D model:

1. Organizational level (O-level): performed on-site, where the equipment is located, for example antenna scheduled maintenance.
2. Intermediate level (I-level): performed on-site, but the equipment is taken to the Production and Maintenance building or Control building for maintenance in a workshop or laboratory.
3. Depot level (D-level): performed off-site – either at OVRO, or at a contractor facility.

With many parts, we will implement a comprehensive logistics support plan. This includes the tracking of maintenance activities and spare parts. An inventory management system will be deployed during the beginning of the implementation phase and will first be used to track pre-production test parts and then rolled out for all construction materials at the Line Replaceable Unit (LRU) level. Ideally, the inventory management system will use bar codes, or a similar radio frequency interference (RFI) friendly mechanism, that can be easily scanned, and updates tracked within the inventory management software.

#### Antenna Maintenance

Antenna maintenance will form a large part of the O-level maintenance load. The antennas are designed for minimum maintenance, including automatic oiling of bearings. Monitor points are designed to identify as many failure modes as possible, including temperatures of mechanical components, drive currents, pointing behavior, solar power system status, etc. These will be used to predict potential failure and allow scheduling outside routine scheduled maintenance.

The most likely failures are currently judged to be the drive motors, which are designed to be easily replaceable, both mechanically and electrically. These and other potential failure components will have defined procedures that will allow repair or replacement in less than a day, including travel time to the antenna. Other mechanical or electromechanical items include bearings, drive belts, encoders, and limit switches. Signal path and monitor and control components will be implemented as LRUs. All maintenance will be designed to not require any equipment that produces RFI.

## Internal/External Communication and Troubleshooting

The operations concept includes a distributed workforce with some staff on site while others are at OVRO, Caltech, and elsewhere. We plan to continue using Slack as the primary means of informal, logged, transparent communication. The communication to site will be primarily through Slack to maintain a log of communication. There will always be at least one person within the main site buildings that is reachable and able to communicate with the on-site observatory staff.

We plan to use Jira as the centralized issue tracker across the system, particularly for any issues related to software, data products, or at system-level. Tracking of hardware-only issues can be tracked within the inventory management system.

The observatory will maintain a periodic telecon (bi-weekly to monthly) and a monthly newsletter is recommended to keep the project’s science community informed. The goal of these is to ensure there is a way for community members to raise any issues identified with the data and to communicate the status of the observations.

## Antenna Access Plan

An antenna access plan will be developed for the final site with the assistance of Praxis Broadband Networks. The access plan will maximize the use of existing roads and use the paths from the fiber optic cable installation to reach each antenna to minimize environmental impact and the creation and proliferation of roads. The paths will be marked using GPS.

# Site Infrastructure Concept

The overarching goal is to minimize infrastructure and environmental impact of the site infrastructure. The location of the buildings is planned to be near the highway midway through the North-South length of the site to minimize the amount of new ground disturbance from the buildings and minimize the amount of trenching needed for the fiber optic network.

Depending on permitting conditions, we plan to truck in water and truck out waste. To aim for net zero power, we will have a combination of grid power and solar power for the buildings. Power can be procured from renewable resources too.

Three buildings will be constructed – a Control Building, including the processing data center, a Maintenance and Fabrication Building, and an Accommodation Building. All services will enter the array at the location of the buildings. For our preferred site, we have identified a location that will use already disturbed land, further minimizing environmental impact.

## Array Infrastructure Concept

The post of each antenna will be driven directly into the soil using a vibratory hammer. This avoids the use of any concrete or cement for the foundations. Each antenna will be connected by fiber optic cable and powered by solar panels and batteries. The solar panels are planned to be attached to a frame that sits on top of the ground. The fiber optic network connecting the antennas will be plowed rather than trenched and has been designed to minimize the amount of plowing required.

## Computer Infrastructure

Where feasible, a containerization framework will be utilized to optimize compute resources. The microservice paradigm plays well with container frameworks especially when the microservice is stateless. Containers also provide software isolation which can include OS flavor and tooling.

### Backups

All software and configuration will exist in Git repos in a cloud service and are automatically backed up. Additional redundancy is provided by the multitude of developers having clones of these repositories on their individual computers.

On-site backups of monitor data and container snapshots can be accomplished using opensource software. The depth of such backups will be limited to hardware and storage costs.

## Site Buildings

We will plan for three buildings:

1. Building 1: The Control Building, which will host all on-site electronics. This building will also include a control room, office and meeting space, and laboratory facilities for intermediate level maintenance. The electronics will be hosted in a data center, with cooling and power management. The building will include electromagnetic shielding to prevent RFI reaching the array.
2. Building 2: A maintenance and fabrication facility, used during construction as a store and antenna assembly workshop, then later during operations to house all the maintenance equipment and workshops.
3. Building 3: Temporary/emergency accommodation for security personnel, staff, visiting scientists and students.

We have identified an old quarry, where we plan to locate the buildings. This will provide additional RFI shielding from the terrain.

### Control Building (Building 1)

The control building will be a building of ~10,000 sq. ft. with a ground floor and a basement. The building will house the hardware for part of the Analog Signal Path, the Radio Camera Frontend, Radio Camera Processor, Pulsar Timing, Data Management, Monitoring and Control, Timing and Synchronization, Observation Planner, as well as all central networking hardware in a basement to help shield radio frequency emission (RF). The building will require plumbing/water and HVAC system capable of maintaining stable temperature for the computer hardware in the basement. A fire suppression system for the data center that is both human and equipment friendly will be installed. If the service entrance is not on the same level as the data center, equipment handling will be provided to transport racks and computers.

The ground floor will contain break room space for daily maintenance workers, lab space to work on electronics, an electronics store for spares, and a basic kitchen.

A rough outline of the building requirements is as follows:

* Space, cooling and power for 100 racks of equipment
* 1 MW power consumption
* Power management systems (UPS)
* Thermal management systems (HVAC or other means for temperature regulation as appropriate)
* Fire suppression system
* The data center will be constructed with a false floor for cool air distribution, and space for cable management and hot air extraction above.

The Control Building will form the hub for on-site activities. It will also host the reception for visitors, although the site buildings are not specifically intended to receive many visitors.

### Maintenance Building (Building 2)

The maintenance will be a large, open building of ~10,000 sq ft. The building can be partitioned appropriately for the project phase. The building will be designed to house vehicles, store equipment, and facilitate the integration and maintenance of antenna parts.

Given the climate at the preferred site, the building will include heating.

### Accommodation Building (Building 3)

The Accommodation Building will provide accommodation for up to 12 people for any potential need for use of the facility overnight. This is expected for security purposes, during commissioning and in case of emergency situations that prevent short term exit from the site or require staff to remain on site. Since all teams will consist of a minimum of two people, 12 rooms will allow two teams across three daily shifts to have accommodation at the same time. The technical support staff are expected to commute daily from Ely and would not routinely use the accommodation facilities.

## Vehicles and Fuel

During operations, the array area will not have any new roads, instead, access to antennas will be by access paths, planned to minimize environmental impact. Enclosed UTVs will be used to perform tasks that do not require a large load capacity. The UTVs are not roadworthy and will only be used in the array. We are planning to procure 4 UTVs for this purpose. Given the climate, the UTVs will be enclosed, with some form of climate control. UTV’s could be electric, or fuel powered – the choice will be based on practical considerations and cost.

For maintenance tasks that require a larger load capacity, as well as transport of equipment to and from the site, 4 off-road capable site trucks will also be purchased. One of these will be used to transport fuel to site for other vehicles (including UTV’s). The regular transport of spares to and from OVRO will also use one of the site trucks.

We expect that customized vehicles with cranes will be used during implementation to install the antennas on pedestals. In case an antenna needs to be removed from the pedestal during operations, we will retain one of these vehicles during operations.

## Power

The total system power is estimated to be 1MW. The bulk of the power is consumed by the computing equipment in the Control Building, which is sourced from the local grid, operated by Mount Wheeler Power for the preferred site.

Mount Wheeler Power has an option to purchase renewable power at a premium. This will be used judiciously to control the sustainability of the telescope. In addition, we will opportunistically install solar panels on the building roofs to reduce the reliance on grid power. This is subject to the power system achieving the required RFI performance, which will be analyzed prior to a decision.

A UPS system in the Control Building will allow graceful shutdown in case of power failure. Since antennas have local solar power, the antennas will automatically enter stow if communications with the Monitoring and Control system is lost.

System startup will be phased to control inrush currents.

The antenna stations will each have a solar power station, with photovoltaic solar panels, batteries, and charge controllers. It is expected that the charge controllers will be custom designed to minimize RFI. The antennas will run from the DC battery power directly, to reduce the need for inverters that can cause additional RFI. The charge controllers will be installed in shielded enclosures with ample filtering of all cables to the panels and antenna.

Antenna station power will be optimized to control downtime due to power outages, rather than to guarantee 100% uptime. A 1% loss due to power availability is built into the system availability model.

Battery maintenance is designed not to perturb the 2-year antenna station maintenance cycle.

## Water

Availability of site water will determine whether water needs to be trucked in, or well water can be used. This will be assessed during the permitting process. Water use is estimated at 40,000 gallons per year, based on experience with water use at CARMA and OVRO.

The baseline water supply, pending the requisite approvals, is from a well with a suitable filtration system. The baseline treatment of sewage is by a septic system. If either of these are not allowed, water will be trucked in, and waste will be trucked out, adding suitable storage systems.

Requirements for water used for wildfire suppression will be assessed in consultation with the Bureau of Land Management and the local community.

## On-Site Communications

The team will use VHF radios (tested and approved for RFI) for communications to coordinate activities in the array area, and safety. A repeater will be installed (if needed) to ensure good coverage across the entire site. Vehicles will have radios, and hand-held units will be available to staff who work in the array.

An emergency IP phone will be available inside electronics enclosures to provide redundant means of communication.

All maintenance communications will be recorded as part of the maintenance logs.

VoIP phones will be available in all buildings for regular or emergency communications.

# RFI Monitoring

Due to the sensitivity and scale of the array, it will be important to track and monitor the RFI environment as well as rapidly identify any degrading changes to the RFI situation. This will be achieved in three ways:

1. Dedicated RFI environment monitoring with a monitor system sensitive enough to cover DSA-2000 requirements.
2. Dedicated RFI surveys on a designated cadence with the DSA-2000 system to capture the RFI environment as seen by the array, and potentially locate any RFI culprits.
3. Analysis and monitoring of the DSA-2000 data itself via raw data and flags.

The RFI monitor system will consist of an antenna which covers the DSA-2000 frequency range (and sufficiently beyond), which will constantly scan and record data. This will give live insight into the RFI situation across the band and provide historic data which can be explored and analyzed via an archive. It is important that the monitor be sensitive enough to represent the environment that DSA-2000 is also sensitive to, although clearly it will be far from the same sensitivity as the array itself.

On an appropriate cadence (e.g., every three months), RFI analysis of the raw and processed data will be performed to compare against the baseline and detect any new signals. This system should be automated as much as possible and can exist as a semi-isolated package which plugs into the relevant data flows. It is likely that ML/AI techniques will be relevant here, particularly to identify new signals of significance that may pose issues for data quality. In the case of new anomalous RFI signals, the automated system will have avenues to flag/raise these with relevant human experts who can assess the data and determine the appropriate course of action.

# On-site safety

A comprehensive Safety Plan will be developed for the site. Dedicated safety staff will be identified and trained in at least:

1. Safety Management
2. First Aid
3. Evacuation Management
4. Fire Fighting
5. Emergency coordination

In addition, in collaboration with BLM, dedicated plans may be developed for:

* Wildfire management and prevention
* Flooding management and prevention
* Earthquake response
* Lightning protection

A site safety officer will be appointed, with alternates as required to ensure there is always a site safety officer on site.

Response plans will also be developed in collaboration with the nearest emergency services, to ensure mutual awareness of activities and capabilities.

# Off-site Support Infrastructure Concept

The nearest town to the preferred site is Ely, Nevada. Ely has a a small but healthy tourism industry that the town is actively developing. Accommodation in and around Ely should suffice for occasional use. The local labor force will be preferentially recruited from the area to ease the difficulty of relocations. More information on Ely is available at several websites, including at <https://elynevada.net/>.

OVRO will serve as the depot level maintenance location, where the operations engineering team will be located. It is envisaged that engineers will periodically visit the site to support the on-site maintenance team with challenging issues. These visits can also serve as transport for spares to and from the site, although a dedicated weekly transport service will also be instituted. OVRO will also host the Test Array, which will serve as a staging platform during operations. All new deployments, whether hardware or software, can be tested in a representative environment at OVRO before deploying to site.

# Transition from Commissioning to Operations

We plan for the array to undergo increasingly comprehensive phases of testing in order to effectively transition to operational readiness. Engineering completion will be verified by acceptance tests, first performed per subsystem, followed by system level testing. These tests will aim to prove that the telescope, or a feature of the telescope, meets the engineering requirements. After acceptance tests are successfully concluded, any new features or functions of the telescope will go through a commissioning phase as part of being integrated into the current state of the operational array.

It will be critical to adopt an approach of consistent integration and testing during construction, in order to identify potential operational challenges as early as possible and have time to adapt or adjust as needed. To that end, we anticipate using early features of the scheduler, monitoring/control and data processing (as well as other relevant subsystems) as soon as possible, and we also aim to be conducting ongoing observational tests with the growing subset of the full array. During the lead-up to construction we will document the expected verification mechanisms for science requirements as part of a science verification plan, and use this to guide the overlapping transition from construction to commissioning to operations. This transition will not be seen as having hard borders giving the nature of telescope construction, and instead we aim to keep many of the same people involved in engineering, commissioning and operations across the construction period (with varying fractional commitment as required).

We will aim to produce early science data as construction progresses, using as much of the full operational workflow as possible, but we expect these earlier data products to be less representative of the final survey data. Where feasible we also intend to use the existing OVRO-LWA and DSA-110 systems as commissioning test platforms for compatible features across the system. Towards the end of construction, we plan to conduct pilot surveys for condensed periods that are as close to representative of the full survey operations mode as possible. We expect the collaboration with the broader science community to be similarly ramping up over the course of construction, with feedback on data quality and science requirements being incorporated throughout the whole process.

# Community Engagement Concept

The public and the local community represent important stakeholders to the project. The remote location and small towns in the area can be substantially changed by the presence of a large project. It is our intention to ensure that any changes are for the better of the communities in the area. The project also holds the potential to create jobs and inspire a new generation of radio astronomers, engineers and technicians.

To support this, an Education and Public Outreach program will be established. This program has two main goals:

1. Train the next generation of STEM Workforce by creating education and training programs that prepare students for the jobs of tomorrow.
2. Foster a science-informed society that appreciates astronomy and radio wave technology's impact on our daily lives and cosmic understanding.

More details are contained in the DSA-2000 EPO Design document, document number D2k-00020-EPO-OTH.

In collaboration with the local community, the project will plan a visitors center in a suitable off-site location. This could be in the nearest town, or next to the nearest main road. Given the low cost of the antennas, it will be possible to place a DSA-2000 antenna at the visitors center.

# Requirements

The following table summarizes the requirements that result from the Concept of Operations.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Reference** | **Requirement Name** | **Requirement Text** | **Notes** | **Cross-reference** |
| COP-0001 |  |  |  |  |

# Acronyms

|  |  |
| --- | --- |
| AI | Artificial Intelligence |
| BLM | Bureau for Land Management |
| CARMA | Combined Array for Research in Millimeter-wave Astronomy |
| CINTEL | Collaborative Intelligence |
| D-level | Depot level (logistics support) |
| DDT | Director’s Discretionary Time |
| DSA-110 | The DSA-110 telescope at OVRO |
| GPS | Global Positioning System |
| HVAC | Heating. Ventilation and Air Conditioning |
| I-level | Intermediate level (logistics support) |
| IP | Internet Protocol |
| IPAC | Infrared Processing & Analysis Center (https://www.ipac.caltech.edu/) |
| IVOA | International Virtual Observatory Alliance |
| LRU | Line Replaceable Unit |
| ML | Machine Learning |
| MTBF | Mean Time Between Failures |
| MTTF | Mean Time to Failure |
| MTTR | Mean Time to Repair |
| O-level | Organizational level (logistics support) |
| OS | Operating System |
| OSBL | Operational Support Baseline |
| OVRO | Owens Valley Radio Observatory |
| OVRO-LWA | Owens Valley Radio Observatory – Long Wavelength Array |
| RF | Radio Frequency |
| RFI | Radio Frequency Interference |
| TBD | To be determined |
| ToO | Target of Opportunity |
| UPS | Uninterruptable Power Supply |
| UTV | Utility Terrain Vehicle |
| VHF | Very High Frequency |