

# Rubin Observatory

Vera C. Rubin Observatory  
Systems Engineering

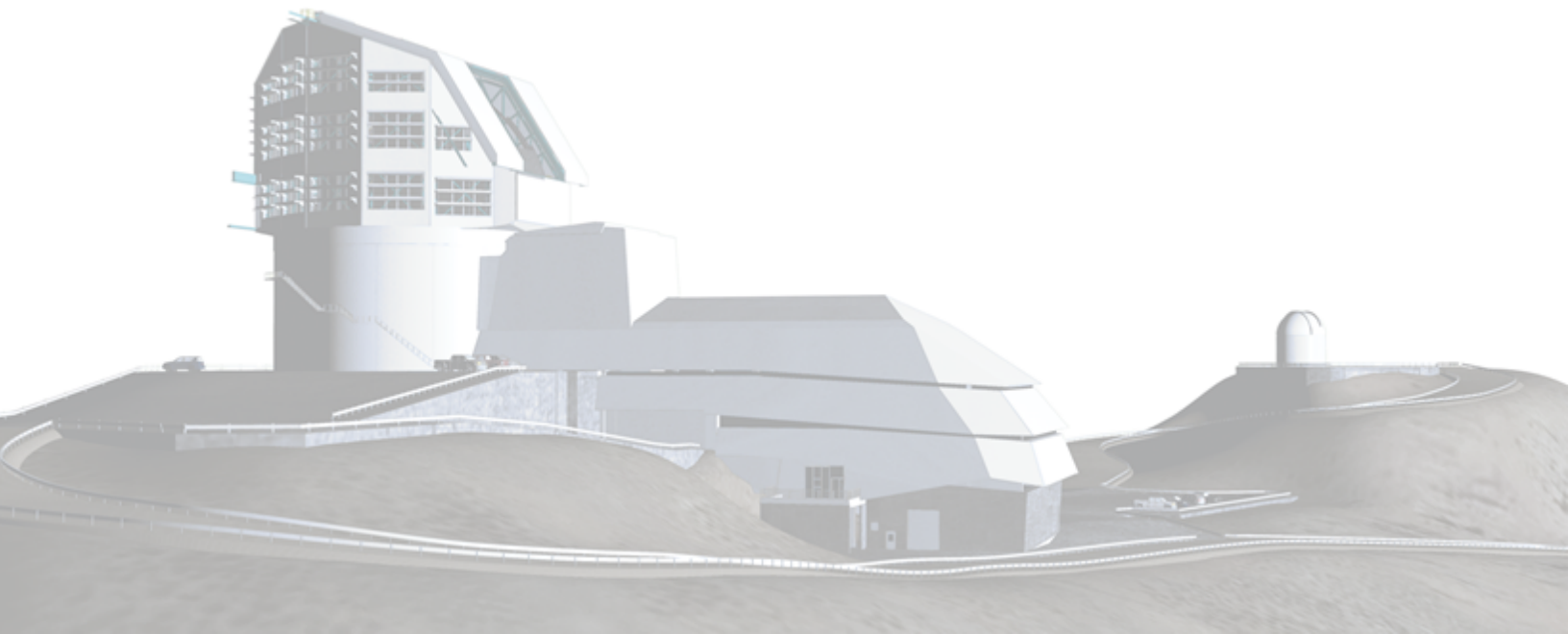
## Operations Readiness Criteria

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## Abstract

This technote collects together the elements that constitute criteria for Operations Readiness of the Rubin Observatory

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# Operations Readiness Criteria

## 1 Introduction

One of the primary high-level strategic inputs to developing the System AI&T and Commissioning Plan (LSE-79) are the construction completeness requirements for the Operations Readiness Review (ORR). At the conclusion of the Commissioning Phase of the LSST construction project an ORR will be undertaken by an external panel, jointly appointed by the DOE and NSF, in consultation with the LSST Project Team. The ORR also signifies the end of the NSF MREFC funded construction project and DOE Commissioning.

We collect together the elements that constitute criteria for Operations Readiness. Each topic has, or will have, defined requirements – in many cases along with goals and stretch goals – that will each have the relevant documentation for performance against the requirement. For those requirements that specify performance after some period of operations, the basis of estimate of projected performance will be provided. Unless otherwise specified, functional requirements will be verified by direct test, and performance requirements will be verified by direct test, analysis, or a some combination thereof. For each requirement, there will either be a clean pass, or there will be a waiver process that documents why it is acceptable to proceed to operations (or the reason we must postpone the transition to operations).

Some of the topics are already covered by existing verification plans. Some functional requirements (and any accompanying goals and stretch goals) are still in review – in those cases, the requirements and associated verifications are being developed together to ensure clarity and verifiability. Some topics, such as the mini-survey, have requirements that are a combination of performance and functionality that do not necessarily flow directly from the high-level requirements; in those cases, we identify the minimum requirements that must be met to proceed to operations, along with a range of goals and stretch goals and the accompanying rationale.

## 2 Verification of Observatory System Specifications (LSE-30)

## 2.1 Construction Completeness Criteria

The project team shall demonstrate that the integrated LSST systems (Camera, Telescope & Site and Data Management subsystems) as well as the Education and Public Outreach (EPO) system have met the technical specifications enumerated in the LSST Observatory System Specifications (LSE-30).

## 2.2 Objectives

The main objective with this Operations Readiness Requirement is to verify the system specifications in the OSS (LSE-30) are proven and well documented.. The OSS is essentially the highest level document describing the basic LSST system architecture. It contains sections derived from the OSS on the following broad topics:

- System Composition and Constraints
- Common System Functions and Performance, including:
  - System Control
  - System Monitoring and Diagnostics
  - System Maintenance
  - System Availability
  - System Time References
- Detailed Specifications:
  - Science and Bulk Data
  - Optical System
  - System Throughput
  - Camera System
  - Photometric Calibration
  - System Timing and Dynamics
- Education and Public Outreach

## 2.3 Criteria or Completeness

Compliance with this objective will follow the process as defined in the Verification and Validation Process document (LSE-160) and associated documentation. All technical specifications in the OSS (LSE-30) and LSR (LSE-29) are expected to be met at the end of construction.

## 2.4 Pre-Operations Interaction

None. Unless there are non-compliance issues against the ORR requirements and specifications.

## 2.5 Artifacts for Completion

- Verification matrix containing entries for all OSS requirements and specifications. Methods, inspections, demonstration, analysis or test, shall be identified for every OSS requirement. Final compliance status will be included.
- Analysis reports where the verification method has been identified as "test" or "analysis".
- Non-compliance reports.

# 3 LSST System Requirements & SRD Verification/Validation

## 3.1 Construction Completeness Criteria

The project team shall characterize and document the performance of the integrated LSST system with respect to the survey performance requirements and specifications enumerated in the LSST System Requirements, Observatory System Specifications and Science Requirements Document (LSE-29, ? & LPM-17 Section 3 respectively).

## 3.2 Objectives

The primary objective for this Operations Readiness Requirement is to verify and validate that the data produced from the science validation surveys (and any additional observing cam-

paings) meets the science verification requirements as described in the LSST Verification and Validation (LVV) elements and test cases. This will include:

- Verification of the generation of all required data products and services;
- Verification that the relevant metadata are being collected and archived;
- Verification of astrometric performance (relative and absolute);
- Verification of photometric performance (relative and absolute);
- Verification of data throughput and processing requirements for prompt data products;
- Completeness and purity of sources detected in AP and DRP;
- Image template generation;
- Completeness and purity of moving object orbit calculations;
- The impact of stray light and optical ghosts;
- Image quality (defined for each subsystem: telescope, camera, data management);
- Crosstalk, filter response, and calibration.

In addition to the normative data quality requirements above, there are several science validation and characterization objectives that represent important benchmarks of scientific capability. The optimization of associated algorithms is in many cases an active research topic, and performance is expected to improve throughout Operations. Potential science validation studies include:

- Object detection completeness;
- Object de-blending;
- Object classification – *e.g.*, star-galaxy separation;
- Galaxy photometry – *e.g.*, for photometric redshifts);
- Difference image analysis photometry – *e.g.*, for statistical variability metrics);
- Low surface brightness features;

- Weak-lensing null tests and shear calibration;
- Treatment of crowded fields.

The verification will make use of Quality Assessment (QA) and Quality Control (QC) tools developed during DM construction.

- Quality Assessment: versatile pipelines to calculate performance metrics and other diagnostics
- Quality Control: ensure that metrics are routinely calculated and track their distributions as the pipelines evolve and encounter new data

In particular, Key Performance Metrics produced by DM and the Commissioning team together with additional test cases will be compared against the tabular requirements in the LSST SRD.

## **Discussion**

For the purpose of evaluating readiness we define the steps associated with verification, validation, and characterization of the LSST data and processing.

*Verification:* Demonstrate that the system as built is consistent with the design. Ensure that the requirements for the system are met using LSST and precursor data. Express the requirements in terms of metrics that can be evaluated using LSST and precursor data. Document the system performance for each of the verification metrics and requirements.

*Validation:* Demonstrate that the system is capable of meeting the scientific objectives of the survey. Ensure that the data products, data access, and science requirements can meet the objectives for LSST's four major science themes. Document the system performance for each of the validation metrics and requirements and verify that there exist mechanisms to monitor the system performance during operations. Validate that the derived data products and access tools meet the science requirements of the community.

*Characterization:* Determine how the performance of the system degrades as a function of environment and technical performance of the components of the system. Measure how the

metrics used in verification change as a function of operational conditions (including weather, site, operations, telescope, instrument, and software).

The scope of science verification and validation activities includes:

- Determining whether the specifications defined in the OSS, LSR, and SRD are being met;
- Characterizing other system performance metrics in the context of the four primary science drivers;
- Studying environmental dependencies and technical optimization that inform early operations;
- Documenting system performance and verifying mechanisms to monitor system performance during operations; and
- Validating data delivery, derived data products, and data access tools that will be used by the science community.

The goal is to quantify the range of demonstrated performance by using a combination of on-sky data, informed simulations of the LSST system, and external datasets. Observations taken during this period will enable higher-level data quality assessments that are not explicitly identified as requirements in the LSR or SRD, but nonetheless represent important benchmarks of scientific performance (e.g., source detection completeness, accuracy of star-galaxy separation, precision of photometric redshifts, and weak-lensing null tests).

All test cases as described under the LSST Verification and Validation project will be implemented as either part of the DM Key Performance Metric validation system, as separate test procedures (e.g., Jupyter notebooks), or via visual inspection (e.g., to demonstrate that a service or data product has been delivered). The LSST Science Platform will be the primary tool for data access and exploration. All metrics will be applied to data from the two main Science Validation surveys (the Wide-area Science Validation Survey and the 10-year Depth Science Validation Survey) and evaluated against the numerical values described in the LSST System Requirements, Observatory System Specifications and Science Requirements Document.

If the schedule for on-sky observations is compressed, there might be a tight timeline for data processing and subsequent analysis of the Science Validation surveys. The statistical power

of tests may be more limited if there are fewer observations. In that case, the validation and characterization may be more limited. For example, if the baseline for the wide-area science verification survey is shortened we will have to verify variability measures (e.g., periods) to specific classes of object. We may want to specify which classes of variability we will prioritize. Similarly, for the data release products, priority might be assigned to the verification of science performance for a brighter sample of objects (e.g., magnitudes  $i < 25$ ).

### 3.3 Criteria for Completeness

The Project team shall complete sufficient science verification, validation, and characterization studies to be confident that 10-year LSST survey can satisfy OSS, LSR, and SRD. Some aspects of science performance are fixed by the telescope, camera, and observing strategy, while others can be continually improved through refinements of the Science Pipelines. In this context, key objectives of science verification are to distinguish between anomalies that can be addressed in the science pipelines and those that are more fundamental to the raw data, and to establish confidence that more subtle anomalies do not fundamentally limit science reach during Early Operations.

To achieve this level of confidence, we identify several essential categories of science performance (in order of increasing algorithmic dependence):

- image quality (PSF FWHM, ellipticity), system throughput, ghosts/scattered light, sky brightness and readout noise, detector anomalies;
- instrument signature removal;
- PSF modeling, photometric calibration, astrometric calibration.

Construction completeness is achieved when LSR and SRD metrics in the categories above pass the design requirements as stated in the SRD. Non-compliance exceptions to the above requirements will be considered following internal and external reviews of the assessed performance and operational impacts.

In addition, substantial progress should be made on towards initial verification of difference imaging, de-blending, galaxy photometry including shape measurement, moving object linkage, and proper motions.

### 3.4 Pre-Operations Interaction

Brief the Operations Team on current status of science verification, validation, and characterization; and

Handoff of QA and QC tools. Ensure that operations team can run these tools, interpret the results, and add new metrics as needed.

### 3.5 Artifacts for Completion

- Minimum:
  - Summary report of system-level science performance metrics, with comparison to specifications in the OSS, LSR, and SRD;
  - Impact study in the case of non-compliance;
  - Documentation of Quality Assessment and Quality Control tools;
  - Draft of Construction Paper for Commissioning Science Verification and Validation (not released until time of public release of commissioning data products).
- Baseline:
  - For each science performance requirement in the LSR and SRD, summary statistic(s) or diagnostic plot(s) demonstrating the distribution of performance and correlations with environmental conditions, astrophysical foregrounds, etc.;
  - Brief reports for a small collection of end-to-end studies demonstrating realistic workflows used for science validation (see examples above). It is envisioned that these studies may mature into full scientific publications during the first year of operations and may involve collaboration with the larger scientific community.

## 4 Science Validation Survey

### 4.1 Operations Readiness Requirement:

The project team shall conduct at least one Science Validation Survey with the science camera (LSSTCam) over a limited area of the sky that will be autonomously driven by the scheduler and will last at least 30 days;

## 4.2 Objectives:

The main objective with this Operations Readiness Requirement is to effectively conduct a “full dress rehearsal” of science operations. The 30-day time span is intended to include operations affected by a full lunar cycle including:

- Filter swapping the u-band during dark time;
- Management of survey scheduling during the period around full moon;
- Scheduler response to a range of environment conditions encountered at the observatory over a 30-day period, including periods of cloud cover and variable atmospheric seeing, variable winds, and changes in daytime / nighttime temperature;
- Response of the LSST Data Facility to sustained data rates including simultaneous execution of the Alert Production and Data Release Production pipelines.

In addition, the following concepts of operations and their procedures will be rehearsed and demonstrated:

- Full rehearsal of safety procedures for science operations;
- Routine daytime maintenance of the observatory;
- Collection and processing of routine calibration data and data products consistent with the time allotted in the 24-hour operations cycle;
- Routine nighttime survey observing operations driven by the scheduler with minimal human interaction, including response to realtime telemetry, AuxTel;
- Demonstration of near real time data quality assessment;
- Prompt processing of alerts within the required latency time (i.e., 60 seconds);
- Recovery from interruptions to observing (e.g. failure of the network)
- Distribution of prompt products;
- Prompt processing and the “24-hour” data products (e.g., asteroid orbit calculations);

- Data Release Production (at least once) and publication to the LSST Science Platform.

Data acquired during the SV survey(s) should be science quality to allow a summative assessment of the delivered scientific performance of the as-built system.

### 4.3 Criteria for Completeness Description:

The baseline schedule of on-sky observations during commissioning concludes with a 8-week period to undertake two science validation surveys. The two surveys are designed to test the Prompt Products and Data Release Products, respectively.

**Wide-area Science Validation Survey:** In a first phase, observe a region of roughly  $1000 \text{ deg}^2$  to an integrated exposure equivalent to 1 year of the Wide-Fast-Deep survey in multiple filters (2 weeks). Create image templates with the Data Release Production pipeline to be used as input for difference imaging. In a second phase starting roughly 4 weeks after the completion of the first phase, observe the same region to an integrated exposure equivalent to 1 year of the Wide-Fast-Deep survey, running the Alert Production pipeline at full scale (2 weeks). The 4-week separation between phases is used for template generation and to allow evolution of variable and transient astrophysical sources between template and test images.

**10-year Depth Science Validation Survey:** Observe a region larger than  $100 \text{ deg}^2$  to an integrated exposure equivalent to the 10-year Wide-Fast-Deep survey in multiple filters (4 weeks). Process the data with the Data Release Production pipeline.

Observation Timeline (baseline): 2 weeks Wide-area Science Validation Survey: Template Generation Phase 4 weeks 10-year Depth Science Validation Survey 2 weeks Wide-area Science Validation Survey: Realtime Alert Production Phase

The wide-area SV survey is designed to approximate the difference imaging templates and data rates that would be expected during early science operations, thus also providing a full-scale test of the LSST Data Facility. The scheduler will drive nighttime observatory operation during the SV surveys.

In event of a shortened period for on-sky observations, we have a draft minimum observing strategy:

- Single-visit KPMs: 6 Star flats in *ugrizy*  $\times$  4 epochs = 4 nights
- Nominal observing for scheduler testing = 3 nights (Note: some scheduler testing will be done during ComCam and LSSTCam integration periods)
- Challenging regions = 1 night
- Full-Depth Survey: 20 year depth in *ugrizy* overlapping at least 1 external reference field, allowing WFD dithers (factor 3)  $\rightarrow$   $\sim$ 5K visits = 8 nights
- Wide-Area Survey: 1600 deg<sup>2</sup> in *gi* filters to 1-year equivalent depth, repeated in two phases  $\rightarrow$  12K visits = 20 nights

Program above is  $\sim$  36 nights total. The essential elements of any observing strategy for the Science Validation surveys are (1) the need to reach 10-year WFD equivalent depth in at least 3 filters in at least one field, (2) to reach 1-year WFD equivalent depth in at least 2 filters over an area exceeding 100 deg<sup>2</sup>, (3) to exercise the nominal scheduler continuously for at least 1 night, and (4) to have coverage to at least 1-year WFD equivalent depth in all 6 filters in at least three fields spanning a range of stellar density. The observatory should operate continuously in scheduler-driven mode for at least 5 days of the 30 days allocated to the Science Validation surveys.

## 4.4 Pre-Operations Interactions:

At the conclusion of the SV Survey(s), roughly two years will have elapsed since the start of Early System Integration and Testing, which places the LSST Observatory on schedule for its 2-year major maintenance and servicing.

**M1M3 Mirror Recoating:** Remove, strip, clean, and re-coat the M1M3 mirror surfaces. Reinstall M1M3 mirror back into telescope. Associated activities include:

- Remove Top-End Integrating Structure with Camera and transfer to Summit Facility camera lab.
- Install camera dummy mass to allow the telescope to point to zenith for removal of the M1M3 mirror cell. Remove M1M3 mirror assembly and transfer to Summit Facility re-coating plant.

- Strip old coating, clean and re-coat mirror surfaces.
- Re-install M1M3 in telescope and prepare to receive the top-end integrating structure with the camera.

Camera Maintenance and Servicing: Clean, service, perform maintenance, and replace shutter. Associated activities include:

- Replace camera shutter with 'fresh' operational unit;
- Inspect, service, or repair filter mechanisms;
- Clean internal camera optics;
- Inspect, service, and repair utility trunk electronics

#### **4.5 Artifacts for ORR:**

- Safety report from continuous observatory operations during the survey(s)
- Summary of daytime and nighttime activity for each 24 hour period of the survey(s)
- Metrics for the effective survey speed, including number of visits per night, telescope slew angles and slew times, filter changes, etc., which can be used to inform survey strategy during early operations
- Characterization of the distribution of data quality delivered by the as-built system, for example, distributions of single-visit image quality and image depth.
- Realtime alert stream
- Associated data release production products accessed via the LSST Science Platform (LSP)
- Pre-ORR observatory maintenance report summarizing the pre-operations engineering activities and current status of the observatory
- Documentation for observatory operations, including recommendations for optimization of data quality and survey efficiency
- Documentation for LSST Data Facility (LDF) operations

## **5 Verification and Validation of Data Management**

### **5.1 Verification Procedure for Data Management System Requirements (LSE-61)**

### **5.2 Prompt Processing**

### **5.3 Data Release Processing**

### **5.4 Rubin Science Platform**

## **6 Community Services and EPO**

## **7 Science Data Quality Assessment**

## **8 Recording and Archiving of System State Metadata**

## **9 Operational Procedures and Technical Documentation**

## **10 As-Built Record, Modifications, non-Compliance and Recommendations**

## **11 Rubin Operations Team Readiness**

## **A References**

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## B Acronyms

Acronym	Description
AP	Alert Production
DM	Data Management
DOE	Department of Energy
DRP	Data Release Production
EPO	Education and Public Outreach
FWHM	Full Width at Half-Maximum
LPM	LSST Project Management (Document Handle)
LSE	LSST Systems Engineering (Document Handle)
LSR	LSST System Requirements; LSE-29
LSST	Legacy Survey of Space and Time (formerly Large Synoptic Survey Telescope)
MREFC	Major Research Equipment and Facility Construction
NSF	National Science Foundation
ORR	Operations Readiness Review
OSS	Observatory System Specifications; LSE-30
PSF	Point Spread Function
QA	Quality Assurance
QC	Quality Control
SE	System Engineering
SRD	LSST Science Requirements; LPM-17