LARGE SYNOPTIC SURVEY TELESCOPE

Large Synoptic Survey Telescope

Scheduler Requirements

DRAFT

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Scheduler Requirements

Summary and Scope

A broad, general, fundamental and formal requirement for LSST is to execute an efficient and effective survey. This imposes functional requirements on the Scheduler algorithms and on the Observatory Control System which utilizes them. The system must execute "a universal cadence that would result in a common database of observations to be used by all science programs". In this document, the Scheduler requirements are founded on the basis of Scheduler objectives, developed to respond to a discrete set of use cases.

The survey must be optimized against local environmental conditions and must adapt according to the external environmental conditions. These requirements implicitly assume timely availability of environmental and related information to the Scheduler, and a scheduler capability to process and utilize this information. The Scheduler requirements are obtained from the OCS Scheduler Requirements, the Observatory System Specifications, part of the OCS Requirements document, and inferred from the Science Requirements Document.

Definitions of Terms

Delivered Image Quality (DIQ) – a measure of the image profile as recorded in the FOV, incorporating all atmospheric, telescope, and detection effects – the full width at half maximum (FWHM) in arc-seconds, or other measure TBD

Field – for simulation purposes, and in discussion here, the available LSST sky is described by a list of fields, each similar in size to the LSST FOV – in survey scheduling, the LSST pointings may be dithered about these positions, or otherwise differ from the field description

Input latency – as used here, input latency refers to the elapsed time between a change in a physical quantity, control information or datum, and the time when the data stream carrying that change is available to the Scheduler

OCS – Observatory Control System, which contains the Scheduler as one of its key components, and among other tasks, performs the visit sequence requested from the Scheduler.

SOCS – Simulated Observatory Control System, a tool which simulates the software environment of the OCS, in order to test and develop the Scheduler; inputs available to the OCS as telemetry must be simulated in the Operations Simulator (OpSim)

OpSim – Operations Simulator, the combination of SOCS and Scheduler interacting with each other to simulate the observatory operations in automated survey.

Proposal – a parameter set describing a spatial region and an observing requirement, passed to the Scheduler for automatic scheduling

Publication – publication of the expected LSST visit sequence in advance of execution

Scheduler – The collection of code which selects the pointing sequence for the survey; this code unit is employed in the Operations Simulator and also in the OCS

Scheduling queue – the Scheduler will enter fields into a queue, with a lead time of 1—2 visits, to enable the OCS to optimally set dome motions – it is assumed here that this queue can be interrupted by the Scheduler if necessary

Scheduling latency – as used here, scheduling latency refers to the elapsed time between a change in the input data available to the Scheduler, and the earliest time when a visit based on that data can commence integration on the sky

Telescope/Survey operator – the responsible person or persons monitoring facility and survey performance in real-time, whether on-site or remotely

Universal cadence – the cadence(s) employed in the main wide-fast-deep survey will be designed to ensure a high degree of uniformity and consistency across the many fields; the actual implementation may consist of different cadences for different fields in any night, but the intergral over the survey will provide the required uniformity.

Visit – A schedule consists of a sequence of pointings, also called visits; a "Standard Visit" consists of two back-to-back 15-second exposures separated by the 2-second readout of the first image and having the last readout in parallel with the re-pointing to the next visit. In some circumstances, the next visit may be to the same field. The exposure time and readout time are current nominal and subject to modification

Reference Documents

"An Optimized Cadence for LSST: The Optimum Unit Method" (Doc-17818)

"LSST Operations Concepts" (TBD?)

"LSST System Requirements" (LSE-29)

"LSST Schedule Publishing Requirement" (Doc-18507)

"LSST Science Book", http://www.lsst.org/files/docs/sciencebook/SB_Whole.pdf

"LSST: From Science Drivers to Reference Design and Anticipated Data Products", Ivezić et al., 2008, arXiv0805.2366I, http://lsst.org/files/docs/overviewV2.0.pdf

"Inputs to OCS Required to Execute LSST Scheduling" (Doc-16283)

"Operations Simulator Requirements" (LSE-189)

"Observatory Control System Requirements" (LSE-62)

"Observatory System Specifications" (LSE-30)

"Science Requirements Document" (LPM-17),

https://docushare.lsstcorp.org/docushare/dsweb/Get/LPM-17

"Use of Weather Forecasts in the LSST Scheduler" (Doc-18505)

Scheduler Requirements

1 Introduction

This document collects the requirements placed on the Scheduler by the Science Requirements Document. Many of these requirements are flowed down through the Observatory Control System and the Observatory System requirements. Others are derived from science-based observing requirements traceable directly to the Science Requirements Document. This document collects Scheduler Objectives, Scheduler Use Cases, and Scheduler Requirements.

This document has been constructed by merger of requirement sets, and there is some redundancy in the following requirements. In the event of apparent inconsistency in requirements herein, the more stringent will be held valid.

1.1 Purpose

The Scheduler objectives have been previously compiled in the proposed Observatory Control System requirements (LSE-62). These objectives cover the functional aspects of LSST observation operations, requiring that observations be scheduled in the most efficient manner, modulo the scientific priorities of the survey. The following subset of proposed OCS requirements documents the flow of Scheduler objectives from the Science Requirements Document.

The functional Scheduler requirements above leave open the question of exactly how to maximize the scientific impact, and what adjustables are needed to conduct the LSST observing campaign that delivers the “best” science.

Owing to the breadth of the requirements for efficiency and optimization of the LSST science performance, other works have informed this document. An ad hoc working group of scientists and engineers explored the science-based requirements for LSST scheduling. This study took into account the participants’ extensive experience in real-world imaging surveys from ground-based telescopes, including how the facility/instrument performance and the evolving environmental conditions trade against survey objectives and survey optimization. Their report, “Science Requirements for LSST Scheduling” (Document-16199) is referenced here as a source of additional motivation for and discussion of some of the topics treated below.

Much of the progress of OpSim has been (and continues to be) research in how to maximize the scientific margin. Version-3 steers the OpSim architecture to address also the Scheduler Requirements, so that OpSim is configured, from here on forward, as the prototype for the Scheduler. The Operations Simulator Requirements document is included here by reference as a source of additional explanation for the following topics.

The foregoing sources have been utilized to generate the collected Scheduler science requirements. These are grouped as specific input and output requirements. Corresponding design requirements are grouped as functional requirements.

1.2 Scheduler Objectives

The Scheduler objectives are derived directly from the Science Requirements Document – specifically, to respond to the need for a universal cadence (possibly implemented by means of multiple cadences, uniformly applied). The Scheduler shall provide an observing program consisting of a sequence of telescope pointings and data acquisition cycles suitable for automated operations. The observing program will be optimized for key science, general science use, and observing efficiency, according to rules or scoring defined and approved by LSST science management and implemented under the supervision of the Scheduler Scientist.

Many of the high level Scheduler objectives have already been concisely formulated as OCS requirements.

1.3 Scheduler Use Cases

The Scheduler use cases (in an Appendix) describe the detailed scenarios in which the Scheduler objectives, listed above, must be achieved, including normal operations, and expected and unexpected deviations from normal. The use cases compiled here are based on material presented at the 2013 All Hands (Document-16406), expanded to include the information recommended by Alistair Cockburn in “Writing Effective Use Cases”. The use cases are based on the circumstances, events and conditions that may be expected to accompany observatory on-sky operations. The Stakeholders are not described for each entry, since these are in all cases the operations staff and the scientific community.

1.4 Latency

Input latency – as used here, input latency refers to the elapsed time between a change in a physical quantity, control information or datum, and the time when the data stream carrying that change is available to the Scheduler. Thus an input datum may be rarely updated (e.g. a forecast) but updated values should be available within the latency period. Several latency ranges have been identified:

1.4.1 Daily

Some parameters are subject to change only by significant intervention – e.g. filter swap. This information will be given a latency of "daily", even though under some conditions a change could take place in the course of a night – the point is, this kind of update is naturally associated with a significant scheduler reset.

1.4.2 Normal

Normal latency is assigned to information which is needed to compute the next visit for addition to the queue. Normally the queue will have a minimum length of several visits, and hence a scheduling latency of ~1.5 minute. Data needed for this purpose should have a latency less than ~1 minute. (A value ~5-30 seconds could be considered, in a cost-benefit trade.)

1.4.3 Urgent

In some cases, information may be immediately useful for such purposes as interrupting the queue, or even interrupting the current visit. Also, some parameters are changing continuously or frequently, and only very fresh information will be accurate. In this case, a minimum latency is needed compared to a single ~40 second visit. (A value ~1-20 seconds could be considered, in a cost-benefit trade.)

2 Specific requirements

2.1 Inputs

All parameter values mentioned in this section are preliminary or notional and subject to review and revision.

2.1.1 Default in Absence of Input

Input may be absent for at least two reasons:

2.1.1.1 The Telemetry System

With failure of the telemetry, the Scheduler will pause and alert the operator.

2.1.1.2 Individual Sources of Telemetry Data

While the telemetry system is functional, individual sources of telemetry data may fail. In order to monitor this possibility, all telemetry data will be accompanied with a currency label with either valid numerical value equal to the age of the data, indicating that the data is sufficiently current to be utilized, or with an undefined value, indicating that the data is unavailable or obsolete. In the entries below, the Default in Absence of Input refers to the action to take in the event that the telemetry is functioning correctly, but the particular data item is classifed obsolete. Most of the items in the Inputs list request an alert to the operator in the event of and Absence of Input. Since such conditions are likely to persist (e.g. failure of an anemometer with a 2-week replacement schedule) the alerts must be managed appropriately.

2.1.1.3 Alerts to Operator

Most of the items in the Inputs list request an alert to the operator in the event of and Absence of Input

2.1.2 Survey Parameters

2.1.2.1 Science proposals coded for Scheduler

ID: OCS-input-01

Specification: All required information describing the needed science observations shall be input to the OCS/Scheduler. Input latency – daily.

Discussion: Science requirements are presented to the Scheduler in the form of proposals. Each proposal encodes all requirements relevant to scheduling, including visit/filter counts, image quality and depth, cadence, and any proposal-specific Scheduler parameters. Parameters currently utilized are listed in a series of documents at:

http://ops2.lsst.org/docs/current/configuration.html

Use in Scheduler: The science proposals can be entered as one of several different standard proposal types, each of which is defined for convenience of implementation. The proposals and proposal types are implementation tools, do not map uniquely to science objectives, and do not describe all science or observing details.

Default in absence of input: Utilize last proposal set, and alert operator.

2.1.2.2 Scheduled Target of Opportunity (TOO)

ID: OCS_input-03

Specification: TOO observations with sufficient lead time shall be pre-scheduled. Input latency – daily.

Discussion: TOO observations may be accommodated. In some cases, the observations will not be so time-critical as to require automated interruption of the normal scheduling process (typically 24+ hour lead time). For these the relevant information will be input to the OCS/Scheduler prior to the observing session, e.g., as new proposals, and will be queued by the Scheduler. To minimize ambiguity, there should always be a TOO file, which may be empty in the case of no planned TOO.

Use in Scheduler: Pre-scheduled TOO observations will be represented in the Scheduler by proposals, possibly of a new proposal type. Each will be active for specified duration(s) with its own requirements and weights. These will be defined prior to the nightly start of observing , and will be “competed” with the standard proposal mix.

Default in absence of input: Assume no TOO, and alert operator.

2.1.2.3 Unscheduled Target of Opportunity (UTOO)

ID: OCS_input-04

Specification: The Scheduler shall accept planned (but unscheduled) TOOs as they are communicated. Input latency – urgent.

Discussion: UTOO observations may be accommodated, based on prior or standing TAC/Director approval. Owing to the urgency of some UTOO observations, the process of inputting to the OCS/Scheduler will be automated, have a latency no greater than the 60 seconds, and will interrupt the ongoing schedule with substituted observations. Following completion of the UTOO, the Scheduler will resume normal activity. To minimize ambiguity, there should always be file of approved UTOO, which may be empty in the case that there are none.

Use in Scheduler: Unscheduled TOO observations will not be processed in competition with the standard proposal mix. They will be processed at highest priority, interrupting the proposal queue at the earliest moment possible after receipt of an authorized observation definition. The required observations will be carried out in the shortest possible time.

Default in absence of input: Assume no approved UTOO, and alert operator.

2.1.2.4 Scripted Schedules

Specification: The Scheduler shall accept scripted schedules of any length up to at least a full night. Scripts will contain an observing sequence, and may include explicit required observing times, and also flags controlling what action to take in the event of an anomaly (pause, halt, restart, skip ahead). Latency – daily.

Discussion: Under some circumstances it may be essential to follow a completely deterministic schedule – which may be difficult or impossible with automated optimizing algorithms. A script may be constructed off-line and by many methods.

Use in Scheduler: Scripts may be used for TOO and for mini-surveys. Autonomous observing could use scripts as stepping stones to optimization (e.g. "An Optimized Cadence for LSST: The Optimum Unit Method").

Default in absence of input: A normal condition, assume no scripted schedules.

2.1.2.5 Avoidance Regions

Specification: The Scheduler shall accept a list of avoidance regions, incuding coordinates, times and other parameters if appropriate, and weights (i.e. a sufficiently high science priority may override a low avoidance priority). This list may be updated continuously based on various inputs. Latency – normal.

Discussion: It may commonly be preferred to avoid observing in certain sky regions owing to factors not accounted for in other ways. Examples possibly include: planets, aircraft flight paths, geostationary satellite positions, reduced telescope performance in certain orientations. To minimize ambiguity, there should always be an avoidace region file, which may be empty in the case of no avoidance regions.

Use in Scheduler: Avoidance region data may be used to assign avoidance weight factors to potential pointings.

Default in absence of input: Pause and alert operator.

2.1.2.6 Downtime Schedule

ID: OCS_input-12

Specification: The current project schedule for downtime shall be available to the Scheduler.

Input latency – daily.

Discussion: Changing the down time schedule in the middle of a night is not a required feature. To minimize ambiguity, there should always be a downtime file, which may be empty in the case of no ascheduled down time.

Use in Scheduler: The downtime schedule is an essential component of Scheduler look-ahead algorithms.

Default in absence of input: Assume no scheduled down time, and alert operator.

2.1.2.7 Backup Programs

Specification: The Scheduler will accept backup programs for possible use when main survey science is not possible. Input latency – daily.

Discussion: Under conditions that do not support main survey science programs (poor image quality, bright sky, excessively variable transparency) it may be possible to carry out valuable alternate science programs. Such programs may be provided.

Use in Scheduler: When the standard science programs do not provide any executable observations (section "Science proposals coded for Scheduler"), the Scheduler will look for executable backup programs and evaluate them with standard Scheduling algorithms.

Default in absence of input: Default to other program if possible, and alert operator.

2.1.2.8 Secondary Programs

Specification: The Scheduler will accept secondary programs for possible use when main survey science is complete. Input latency – daily.

Discussion: The completion of science programs cannot be precisely predicted owing to the variabiilty of conditions. When a program does complete, there are several options, including: the program can restart, it can continue with the objective of improving quality or homogeneity, or it can be terminated. In any case, alternate programs may be activated, with appropriate priority parameters.

Use in Scheduler: When a program completes, the disposition of the program may be defined within the program parameters, or by ad hoc decision processes external to the Scheduler such as observatory policy or executive decision. Likewise, backup programs may be entered into candidacy by similar process.

Default in absence of input: Default to other program if possible, and alert operator.

2.1.3 Scheduling Parameters

2.1.3.1 Scheduler algorithm/parameters

ID: OCS_input-02

Specification: Scheduler control parameters shall be input to the OCS/Scheduler. Input latency – daily

Discussion: The performance of the Scheduler algorithm(s) depends on the configuration file-based parameters, which include descriptions of hardware performance, and weights and switches controlling Scheduler operation. While a single parameter set is expected to serve automatic scheduling under typical conditions, it is possible that for some conditions (unexpected instrument failure modes or observing conditions) it will be necessary to swap to a different Scheduler algorithm or instrument performance model during an observing session.

Use in Scheduler: The scientific performance of the Scheduler operation is controlled primarily by the configuration parameters, which describe the sky areas to be surveyed, the required observations, the cadences, and the weights to be employed in scheduling. The Scheduler bases its selections on a detailed model of telescope performance, which is also described by configuration parameters.

Default in absence of input: Pause and alert operator.

2.1.4 System Parameters

2.1.4.1 Restrictions on Pointing

ID: OCS_input-09

Specification: The current facility restrictions on pointing shall be available to the Scheduler. Input latency – urgent.

Discussion: Pointing restrictions (including telescope, dome, cable wrap information) are parameters in the Scheduler that must be updated any time that the telescope operational limits change. The restrictions currently implemented, along with other configuration parameters, are described at http://ops2.lsst.org/docs/current/system.html To avoid ambiguity, there will always be a file of pointing restrictions, which may be empty if there are none.

Use in Scheduler: The Scheduler will update its instrument description with the pointing restriction information.

Default in absence of input: Pause and alert operator.

2.1.4.2 Focal Plane Description

ID: OCS_input-10

Specification: The description of the LSST active focal plane shall be available to the

Scheduler. Input latency – daily.

Discussion: The LSST focal plane is complex and performance of parts of it may vary. Information about the focal plane, particularly about changes which impact science throughput, may be useful to the Scheduler. A useful description would be a map of relative performance, showing both full and partial failures. [Viz. Camera-DM ICD.]

Use in Scheduler: The Scheduler will maintain several focal plane performance descriptors, at least including:

- Fractional effective area relative to nominal (i.e., reduced to account for any inactive chips or rafts).
- Noise degradation as fractional increase in median detector read noise over active focal plane area relative to nominal.

This information may be used to temporarily adjust the priority of some proposals or some observations.

Default in absence of input: Full focal plane operation assumed, and alert operator.

2.1.4.3 Telescope Performance Status Assessment

ID: OCS_input-11

Specification: The telescope performance status assessment shall be available to the Scheduler. Input latency – normal.

Discussion: Following OCS requirement **OSS-REQ-0029**, the performance of actual telescope scheduling relative to the requested scheduling will be assessed at least every hour. The result of this assessment will be available to the Scheduler. In the event of deteriorated performance, immediate alert to the telescope/survey operator will be required.

Use in Scheduler: There will be pre-established tolerances for basic functions (slew, settling, filter change, etc). For performance within tolerance but systematically differing from the model, some compensation within the Scheduler may be applied. For performance outside tolerance in any parameter, a protocol for operator intervention will be initiated.

Default in absence of input: Pause and alert operator.

2.1.5 Internal Conditions

2.1.5.1 Operating status

ID: OCS_input-05

Specification: The operating status shall be available to the Scheduler. Input latency – urgent.

Discussion: The operational status of the facility will be available to the Scheduler, indicating the current state, which might include (ready, pending, closed) and possibly other information.

[Note: the complete status description will be defined elsewhere in LSST documentation, viz. future Technical Operations Document.]

Use in Scheduler: When "ready" the Scheduler will operate in normal scheduling mode, issuing observation requests at a normal cadence. When the status is "pending", the Scheduler will repeatedly update its observation request queue, but not execute it. When observing is neither "ready" nor "pending", the Scheduler will be inactive.

Default in absence of input: Scheduler will pause when status is not "ready"

2.1.5.2 Filter in Use

ID: OCS_input-06

Specification: The identity of the filter in use shall be available to the Scheduler. Input latency – urgent.

Use in Scheduler: The Scheduler will update its instrument description with the current filter information.

Default in absence of input: Assume last commanded position and alert operator.

2.1.5.3 Filters Available

ID: OCS_input-07

Specification: The identity of the filters available shall be available to the Scheduler. Input latency – daily.

Discussion: the selection of available filers will change when the any filter is swapped, or when any filters are withdrawn for any reason. Change will occur during between observing sessions, not during.

Use in Scheduler: The Scheduler will update its instrument description with the available filter information.

Default in absence of input: Pause and alert operator.

2.1.5.4 Current Camera Rotator Position

ID: OCS_input-08

Specification: The current camera rotator position shall be available to the Scheduler. Input latency – urgent.

Use in Scheduler: The Scheduler will update its instrument description with the current rotator information.

Default in absence of input: Assume last commanded position assumed and alert operator.

Do not request any rotator motions from the Scheduler without current position information.

2.1.6 External Conditions

2.1.6.1 Processing of telemetry

Current external conditions will be monitored by a variety of measurement devices. The resulting data streams will require various degrees of processing. For example, sky brightness measurements in a test device filter set may require transformation to the LSST filter set. DiMM seeing measurements may require averaging and scaling for useful comparison to quick-look seeing measurements. It is assumed here that this processing is external to the Scheduler, and that the latency describes access to the processed data.

2.1.6.2 Weather Forecast

Weather forecast data will be made available to the Scheduler as it becomes available. This will be useful in determining the probability that observations can be acquired at various times in the future – this information is essential to Scheduler look-ahead.

The raw forecasts will require a variety of processing, and will likely be merged with statistical information for the time period beyond the forecast range. This processing is here assumed to be external to the Scheduler. If internal, some of the following may change.

The latency of forecasts should be limited by the forecast data sources, with typical cadence of once per 30 or 60 minutes.

The possible detailed uses of weather forecast are discussed in "Use of Weather Forecasts in the LSST Scheduler".

2.1.6.2.1 Precipitation Forecast

ID: OCS_input-14

Specification: The forecast for amount of precipitation vs time shall be available to the Scheduler. Input latency – normal.

Use in Scheduler: In scheduling look-ahead, time periods with predicted precipitation may be given reduced weight.

Default in absence of input: Forecast of no rain assumed, and alert operator.

2.1.6.2.2 Cloud Forecast

ID: OCS_input-15

Specification: The forecast for cloudiness vs time shall be available to the Scheduler. Input latency – normal.

Discussion: Useful information about clouds includes the fractional sky cover, altitude, and cloud type, as typically available from aviation forecasts.

Use in Scheduler: In scheduling look-ahead, time periods with clouds may be given reduced weight.

Default in absence of input: Forecast of clear weather assumed, and alert operator.

2.1.6.2.3 Forecast for Passage of Fronts

ID: OCS_input-16

Specification: The forecast for passage of fronts shall be available to the Scheduler. Input latency – normal.

Discussion: As weather fronts are commonly associated with turbulent conditions, this information can be useful in projecting the probability of obtaining useful data.

Use in Scheduler: In scheduling look-ahead, time periods with predicted passage of fronts may be given reduced weight.

Default in absence of input: Forecast of no fronts assumed and alert operator.

2.1.6.2.4 Temperature and Rate of Change with Time

ID: OCS_input-17

Specification: The forecast for the ambient temperature and temperature change shall be available to the Scheduler. Input latency – normal.

Discussion: Temperature and temperature changes may strongly impact dome seeing, and may correlate with increased free atmosphere turbulence. Normal diurnal variation is 1-2 deg-C per hour, and is associated with moderate image quality degradation.

Use in Scheduler: In scheduling look-ahead, time periods with predicted temperature gradient greater than normal may be given reduced weight.

Default in absence of input: Typical nightly profile assumed and alert operator.

2.1.6.2.5 Wind Speed and Direction

ID: OCS_input-18

Specification: The forecast for the wind and wind direction shall be available to the Scheduler. Input latency – normal.

Discussion: Local wind is associated with turbulence, poor seeing, and telescope wind shake; hence it is an important predictor of observing conditions. Winds aloft (vertical profile of wind speed and direction) are a major contributor to the apparent motion of clouds.

Use in Scheduler: Several wind speed break points may be identified, corresponding to possibility of wind-shake, possible restriction of pointing, and possible closure. In scheduling look-ahead, these forecast intervals may be given reduced weight.

Default in absence of input: Forecast of average wind speeds assumed and alert operator.

2.1.6.2.6 Precipitable Water Vapor

ID: OCS_input-19

Specification: The forecast of precipitable water vapor shall be available to the Scheduler. Input latency - normal.

Discussion: The water vapor in the telescope line of sight will impact the throughput of the z and y filters, and variations in the water vapor will complicate photometric calibrations.

Use in Scheduler: In scheduling look-ahead, time periods with high or varying water vapor may be given reduced weight.

Default in absence of input: Forecast of average (seasonal) water vapor assumed and alert operator.

2.1.6.3 Current Meteorology

Telemetry from local sensors will stream readings on local atmospheric parameters that impact observing conditions.

2.1.6.3.1 Cloud Cover

ID: OCS_input-20

Specification: The current cloud cover over the observatory shall be available to the Scheduler. Input latency – urgent.

Discussion: The bulk cloud cover is an indicator of the kind of scheduling input required to provide an optimized program. In the case of minimal cloud cover, it may suffice to avoid cloudy regions, and maintain high efficiency, whereas during heavier cloud cover it may be necessary to hunt for useful zones, with lower efficiency, or possibly switch to a back-up program. Transparency, including transparency through thin clouds, is specified elsewhere.

Use in Scheduler: If current cloud cover is greater than zero the Scheduler may take into account the instantaneous cloud distribution in determining which portions of the sky are available for observation. Under difficult conditions, the operator may have the option of switching to a back-up observing plan. In look-ahead, the near future may be given reduced weight.

Default in absence of input: Zero cloud cover assumed and alert operator.

2.1.6.3.2 Environmental Temperature Sensors

ID: OCS_input-21

Specification: A variety of temperature data streams shall be available to the Scheduler. Input latency – normal.

Discussion: Temperature drifts and differentials are a good predictor of the incidence of dome seeing, and combined with wind information may allow optimizing of the field selection to minimize the impact of dome seeing. For example, if the primary mirror is warmer than the ambient air, the best image quality may be obtained by orienting the dome to allow a moderate wind to sweep away turbulent cells.

Use in Scheduler: In scheduling look-ahead, if the mirror temperature is greater than the ambient dome temperature, the near future may be given reduced weight.

Default in absence of input: Stable temperatures assumed and alert operator.

2.1.6.3.3 Wind

ID: OCS_input-21

Specification: The external wind speed, direction, RMS and peak values, and the dome interior wind speed, shall be available to the Scheduler. Input latency – urgent.

Discussion: Wind information for the free atmosphere will help to optimize field selection with respect to potential wind buffeting – for example by selecting fields that orient the dome to protect the telescope. The wind speed inside the dome will provide additional information on the success of wind palliative efforts.

Use in Scheduler: Several wind speed break points may be identified, corresponding to possibility of wind-shake, possible restriction of pointing, and possible closure. In scheduling look-ahead, the immediate future may be given reduced weight.during high wind periods.

Default in absence of input: Alert operator and pause within 10 minutes pending operator intervention to override.

2.1.6.4 Sky Conditions from Auxiliary Monitors

Sky conditions provide the strongest variable constraint on data quality, and are subject to rapid stochastic variations. The sky conditions will be tracked by several observatory resources, including an all-sky photometric camera, a photometric monitoring telescope, and a DIMM seeing monitor. These instruments will provide data streams which, in general, will require analysis to provide the useful sky condition measures needed for scheduling.

The Scheduler inputs will be derived from a combination of current measurements, combined with models and analysis.

2.1.6.4.1 Free atmosphere seeing

ID: OCS_input-22

Specification: The current free atmosphere seeing along one sight-line shall be available to the Scheduler. Input latency – normal.

Discussion: The free atmosphere seeing, as from a DIMM, is a reference point for the best possible delivered image quality. If the delivered image quality is significantly inferior than expected, based on the free atmosphere measurement, more judicious selection of fields may ameliorate the effect. The CTIO RoboDIMM (http://www.ctio.noao.edu/telescopes/dimm/dimm.html) is a satisfactory model for the minimal instrumentation, with a data product approximating the zenith-equivalent r band seeing and a cadence of no greater than 1 minute. DIMM measurements are based on a single narrow line of sight, and have strong fluctuations, hence require filtering in addition to scaling to the appropriate filter and zenith distance. It is assumed here that this is done externally to the Scheduler.

Use in Scheduler: If the predicted image quality based on the DIMM and the observed image quality from the data pipeline differ significantly, the operator will be notified. S(he) will have the option of reducing the weight of parts of the sky (e.g. the parts in the windward quadrant). This will also serve as an alert to possible system malfunction.

Default in absence of input: Median image quality assumed, and alert operator.

2.1.6.4.2 All-sky Sky brightness

ID: OCS_input-23

Specification: A calibrated all-sky map of the sky brightness in all filters (some likely transformed or scaled from others) shall be available to the Scheduler. Input latency – urgent.

Discussion: Sky brightness provides a systematic background, limiting deep imagery. It is extremely variable, both systematically due to lunar phase, and irregularly depending on clouds, atmospheric aerosol and particulate content and solar/geomagnetic activity. A continuous direct calibration of the sky brightness is essential to evaluate and to update in real time the Scheduler sky brightness model to predict current and near future conditions with the best possible confidence. The back-scatter of moonlight off thin clouds makes a big difference, and changes quite rapidly. The science requirement asks for sky brightness estimates in all 6 bands with spatial resolution of 30 arcminutes and precision and accuracy of 0.1 mag rms in all bands. (These numerical values are provisional and subject to review. The feasiblity of extracting such data from external monitoring devices remains to be demonstrated.)

Use in Scheduler: In scheduling, the selection of pointings depends on the required and actual sky brightness. Actual sky brightness, when available, will be used for scheduling purposes, in preference to model sky brightness. If the sky brightness based on the all-sky monitor and the observed sky brightness from the data pipeline differ significantly, the operator will be notified. S(he) will have the option of reducing the weight of parts of the sky, e.g. the dusk or dawn horizon, or within a specified angle of the moon.

Default in absence of input: Model sky brightness assumed, and alert operator.

2.1.6.4.3 All-sky Transparency

ID: OCS_input-24

Specification: All-sky maps of the atmospheric transparency in the *ugrizy* filters shall be available to the Scheduler. Input latency – urgent.

Discussion: Atmospheric transparency contributes to limiting the depth of imagery, and variations in transparency complicate photometric calibrations. It is irregularly variable, depending on atmospheric aerosol and particulate content. A continuously available map of transparency is needed for selecting fields, and the time history of transparency is a useful discriminant for photometric/non-photometric conditions. The science requirements ask for atmospheric transparency information in ugrizy with a temporal cadence of not less than 2 minutes, and an angular resolution of 30 arcminutes. Units are magnitudes of extinction, assuming an AB-flat source SED. This will include (on the basis of measurements or validated models) all sources of extinction, including clouds, aerosols, Rayleigh scattering, and molecular absorption including water vapor. Values for some filters will be computed from measurements in other filters. The requested precision of the attenuation estimates is 0.05 magnitudes rms in griz and 0.1 mag in u and y. (These numerical values are provisional and subject to review. The feasiblity of extracting such data from external monitoring devices remains to be demonstrated.)

Use in Scheduler: In scheduling, the selection of pointings depends on the required and available 5-sigma detection limit. The transparency is a factor in the calculation of the 5-sigma detection limit. Actual sky brightness, when available, will be used for scheduling purposes, in preference to model sky brightness.

Default in absence of input: Median transparency assumed, with correction for precipitable water vapor, if available,and alert operator.

2.1.6.4.4 All-sky Photometric Quality

ID: OCS_input-25

Specification: An all-sky map of the photometric quality as a function of position on the sky, in at least one visible filter, shall be available to the Scheduler. Input latency – normal.

Discussion: Both relative and absolute photometric quality are essential parameters in the LSST survey. Both may be inferred to some degree from the stability of all-sky transparency. This can be estimated from photometry on an all-sky grid of bright stars. The spatial variation in transparency in rms magnitudes, as a function of zenith distance, will be provided as a measure of photometric uniformity across the sky. The temporal trend of these numbers in magnitudes per hour will be used as a measure of photometric stability.

Use in Scheduler: In Scheduler look-ahead, time periods with enhanced photometric variability at constant zenith distance may be given reduced weight.

Default in absence of input: Normal good photometric stability assumed, and alert operator.

2.1.7 Sky Conditions from Recent Images

2.1.7.1 Data Pipeline Quick Look and Data Quality Processing

Under most circumstances, the most reliable indicator of the conditions expected in the near future will be the conditions in the recent past. The actual data acquired in the most recent observation will reflect the impact of all those conditions, including all the effects discussed in the above draft requirements. Rapid return of pipeline processing results as input to the OCS/Scheduler will be essential and invaluable.

2.1.7.2 Sky brightness in Recent Images

OCS_input-27

Specification: The median sky brightness in the most recent image, with associated observing parameters, shall be available to the Scheduler. Input latency – urgent.

Discussion: The observed sky brightness will vary across the focal plane, owing to the vignetting function. The brightness will be expressed by its vignetting-corrected median value, in magnitudes per arcsecond squared, and its rms about the vignetted value, with correction to constant elevation. For short slews, staying in the same filter, the most recent image will provide the most useful sky brightness measurement. For long slews or filter changed, the sky monitor will give more reliable current sky brightness values.

Use in Scheduler: The current sky brightness is the best estimate for the sky brightness in the next image. In Scheduler look-ahead, time periods with enhanced sky brightness may be given reduced weight. If the rms sky brightness is enhanced beyond a benchmark value over spatial scales that are problematic for photometry, the observation may be tagged as failed.

Default in absence of input: Model sky brightness assumed, and alert operator.

2.1.7.3 Transparency in Recent Images

ID: OCS_input-28

Specification: The transparency across the FOV inferred from the most recent image shall be available to the Scheduler. Input latency – urgent.

Discussion: Non-uniformity of transparency will complicate photometric calibrations and limit their success. The use of difference images for detection of alerts will facilitate the measurement of transparency and its variations across the FOV. Temporal variation of transparency may suggest difficulty in absolute calibrations. Spatial variation in trasnparency over scales that are problematic for photometry may suggest difficulty in relative calibration. The vignetting-corrected transparency in magnitudes, and its RMS variation on selected spatial scales will be provided. For short slews, staying in the same filter, the most recent image will provide the most useful transparency measurement. For long slews or filter changed, the sky monitor will give more reliable current transparency values.

Use in Scheduler: If the rms transparency is enhanced, the observation may be tagged as failed. In Scheduler look-ahead, time periods with compromised transparency may be given reduced weight.

Default in absence of input: Median transparency assumed, and alert operator.

2.1.8 Performance Feedbacks

2.1.8.1 Delivered Image Quality (DIQ)

ID: OCS_input-26

Specification: The median DIQ from the most recent image, with associated observing parameters, shall be available to the Scheduler. Input latency – urgent.

Discussion: The report on the DIQ should include seeing FWHM, which reveals primarily the effects of the atmosphere, and the image shape, described by ellipticity, which reflects the performance of the fixed and active optics. Some of this information will be a function of the position on the focal plane, and how to represent is TBD.

Use in Scheduler: In scheduling, the selection of pointings depends on the required and available image quality and on the 5-sigma detection limit. The image quality is a factor in the calculation of the 5-sigma detection limit. Observed DIQ may be used to tag an observation as failed. In Scheduler look-ahead, time periods with poor DIQ may be given reduced weight.

Default in absence of input: Median image quality assumed, and alert operator.

2.1.8.1.1 Success of Current Exposure

ID: OCS_input-29

Specification: A success/fail flag shall be available for the current exposure. Input latency – urgent, for failed exposures, normal for successful exposures.

Discussion: in order to maintain an accurate queue, the Scheduler must assume that queued observations will be, and have been, successful, until declared otherwise. A declaration of failed could come quickly, while a declaration of success could have a lag of ~1-2 minute. The Scheduler history and queue must be self-healing regardless of the timing.

Use in Scheduler: Immediate identification of a failed observation will enable the Scheduler to reset the priority of the observation while the telescope is still pointing in the near vicinity of the field, increasing the probability that the schedule sequence will self-repair immediately. The Scheduler may implement an "instant" repeat decision, possibly science proposal dependent. For each failed observation, the observing history will be corrected to reflect this fact immediately, allowing the Scheduler to include a re-observation as one of the candidate observations for the next evaluation cycle. Notify operator for all failed exposures.

Default in absence of input (or pending input): Successful exposure assumed.

2.1.8.1.2 Operator Anomaly Flag

ID: OCS_input-30

Specification: The telescope/survey operator can trigger an observation anomaly flag which shall be available to the Scheduler. Input latency – urgent.

Discussion: There may possibly be observatory anomalies that the standard monitors do not log (e.g. change from line to local power, minor tremor, inadvertent dome illumination). An operator initiated anomaly notification will be recorded with the visit metadata. It will not trigger Scheduler action unless so preprogrammed in the Scheduler (TBD)

Use in Scheduler: Operator intervention will be noted in the observing record, with explanatory information.

Default in absence of input: No anomaly assumed.

2.1.8.2 List of Archived Visits

ID: OCS_input-31

Specification: A list of past visits for the partial duration of the survey shall be available to the Scheduler. Input latency – daily.

Discussion: The Scheduler will have access to the catalogue of completed visits integrated over the entire survey, up to and including the previous night, with associated data quality information.

Use in Scheduler: The Scheduler will maintain an internal up-to-date history of observations. As further discussed below (section "Scheduler History"), the scheduler will assemble this history from the archive of previous nights, augmented with the additions of the current night. The archived history is essential for the warm-start of the Scheduler at the beginning of each night, after a software update, a reconfiguration of science programs, or any other substantial interruption or reset.

Default in absence of input: If an out-of-date archive is available, use it as basis for scheduling. If no archive is available, restart survey. In any anomaly, alert operator.

2.2 Outputs

All parameter values mentioned in this section are preliminary or notional and subject to review and revision.

2.2.1 Next Target

Specification: The next target shall be published by the Scheduler with all the necessary parameters to perform the observation right after the last active visit.

Discussion: The parameters describing the next target include but are not limited to:

- field ID, filter,
- list of proposals, list of sequence IDs, list of values, target rank
- part of a deep drilling event
- RA, Dec, Angle,
- number of exposures, list of exposure times,
- expected LST, mount-Alt, mount-Az, Rot, dome-Alt, dome-Az at start of first exposure
- expected maximum speeds for mount-Alt, mount-Az, Rot, dome-Alt, dome-Az during slew
- expected slew time
- expected airmass, sky brightness at start of first exposure
- expected seeing, transparency at start of first exposure

2.2.2 Predicted Schedule

Specification: The Scheduler shall publish the predicted schedule of visits right after the posting of the next target to the queue. Configuration parameters will adjust the length of the published list, and the weight governing the priority of adhering to the previously published schedule as opposed to diverging from the published schedule in response to changed environmental conditions or other parameters.

Discussion: The need for target publication is discussed in "LSST Schedule Publishing Requirement". The length of the published interval is a configurable parameter and will be adapted to the operational needs and the available Scheduler performance. The predicted schedule considers the deterministic look-ahead models, the expected system performance, the current weather conditions and the available forecast. Any change in the actual values may produce a different schedule of visits, due to the dynamic and adaptive nature of the Scheduler. Under some science scenarios, it may be appropriate to follow the published schedule even when conditions have changed so that the published schedule is no longer optimum according to the scheduling algorithm.

2.2.3 Scheduling meta data

Specification: For each requested target, the Scheduler shall publish metadata containing information about the selection process for that target, values, costs and intermediate calculations, as well as alternate targets, to analyze the scheduling algorithms a posteriori.

Discussion: The number of alternate targets is a configurable parameter, depending on the analysis needed on the behavior of the Scheduler.

2.2.4 Survey progress

Specification: The Scheduler shall provide a set of indicators for reporting the progress on each science proposal and the overall survey, in the technical quantities that are part of the goals in its algorithms.

Discussion: The indicators to report are but are not limited to following;

- elapsed time
- percentage of visits in each proposal and filter considering the goal number of visits
- average completion of sequences per proposal and per filter
- distribution of completion of the sequences
- percentage of achieved tuples in corresponding science proposals

2.3 Functional Requirements

2.3.1 Observatory Model

Specification: The Scheduler shall include an observatory model to estimate the slew delay time to any potential target. The model shall include the relevant elements of the observatory that participate in the slewing to a target, and shall describe them in the necessary detail to compute the contribution to the delay time.

Discussion:

- Mount Altitude: for mount altitude axis a second-order model is considered. There is a lower limit and a higher limit for the telescope altitude position, a constant acceleration, a maximum speed and a constant deceleration. The speed limit, acceleration and deceleration are the same for both directions, and are independent of the azimuth position.

- Mount Azimuth: for mount azimuth axis a second-order model is considered, constant acceleration and deceleration with a maximum speed, all the same for both directions. A cable-wrap is included in the model, allowing a range of movements for more than a full circle. An absolute minimum limit and an absolute maximum limit are defined (-270 and +270 degrees), and the absolute azimuth moves in this range. For some target positions there are 2 possibilities, the closest to the current absolute position is chosen for determining the distance and direction for the delay computation.

- Rotator Angle: for mount rotator axis a second-order model is considered. The absolute angle limits allow a range of half circle, the limits are -90 and +90 degrees. Besides the parameters minimum angle, maximum angle, acceleration, deceleration and maximum speed, this component has an additional one, “follow sky”, which controls the orientation of the image. If this parameter is enabled, the target angle for the rotator will follow the parallactic angle to put North up (or down according to the range possibilities). If this parameter is disabled, the rotator angle is left where it is during the slew, but it tracks during the exposure.

- Dome Azimuth: for dome azimuth axis a second-order model is considered, with its own maximum speed, constant acceleration and deceleration, with no cable-wrap limits.

- Dome Altitude: for dome altitude axis a second-order model is considered, with its own maximum speed, constant acceleration and deceleration.

- Telescope Optics Correction: For the active optics corrections model, no coordinates for active components are tracked. A very simple model computes the time delay to adjust the optics as a function of the altitude slew in the telescope. There are 2 components in this model: the open-loop corrections and the closed-loop corrections. Both delay components need to be added because the eventual closed-loop correction is always executed after the open-loop correction. For the open-loop corrections model, the assumption is that correcting from the look-up tables is fast enough or not needed during tracking, so there is a penalty only when correcting for the slew. This penalty is modeled as a constant rate in time/altitude-angle-distance for the whole altitude range. For the closed-loop corrections, the supposition is that there is a first range of altitude-angle-distance (between 0 and a defined *limit1*) for which no correction is needed. There is a second range (between *limit1* and *limit2*) for which a single exposure is needed for the correction, adding a penalty of a constant delay time. Finally there is a third range (between *limit2* and 90 degrees) for which 2 consecutive corrections are needed producing a longer delay time.

- Settle Time: The settle time is a constant delay applied to every slew and accounts for damping the possible vibrations in the mount.

- Filter Change: a model of the filter changer mechanism is considered, with enough detail to calculate the filter change time to a specific filter position.

- Readout: This is the delay in the readout for the previous exposure, considered part of the following slew.

- Shutter time: This is the time needed to open and close the shutter.

- Visit Time: This is time elapsed from the start shutter open of the first exposure of the visit, to the end shutter close of the last exposure of the visit. Depends on the number of exposures in the visit, the time of each exposure, the shutter time and the inter-exposures readout time.

2.3.2 Update of the Observatory Model

Specification: The Scheduler shall be capable of receiving updates of the observatory model parameters, adapting to the actual behavior of the system and keeping the needed accuracy for slew time cost calculations and deterministic look-ahead.

2.3.3 Scheduler History

Specification: The Scheduler shall maintain a complete history of the past schedule of actual visits.

Discussion: The internal history of visits is independent from the external Engineering Facility Database. This internal history keeps not only the visit parameters from the observation point of view, it also carries metadata produced by the relevant science proposals that are of interest to rank new targets in the present and the future. In a warm-start, this history is totally rewritten by the new set of science proposals based on the past history externally kept in EFD (section "List of Archived Visits"). This allows adaptation of the survey to new algorithms and new proposals, without losing potential credit on the past history.

2.3.4 Science Proposals

Specification: The Scheduler shall incorporate multiple science proposals for target generation.

Discussion: The science proposals are the objects whose role is to propose targets to the Scheduler at each observation moment, giving a numeric rank to each candidate target according to their own agendas. Each proposal has its own scientific objective and individual characteristics.

The parameters that define a specific science program include but are not limited to:

- Sky region
- Number of visits per field in each filter
- Cadence constraints for revisits or sequences
- Airmass limits
- Sky brightness constraints
- Seeing requirements
- Activation times
- Number of exposures per visit and exposure times

2.3.4.1 Scripted Proposals

Specification: A scripted proposal follows a preconfigured list of targets to be proposed sequentially without any prioritization. The list of sequential targets is provided in a configuration file, with proper start times for the nightly list.

Discussion: Scripted cadences will be required for a variety of commissioning, testing and calibration functions, and may be a suitable way of implementing special fractions of the survey.

2.3.4.2 Target of Opportunity Proposals

Specification: The Scheduler shall offer an interface and the capability to execute targets of opportunity.

Discussion: A proper template needs to be defined, in which the specification of the targets, constraints, time windows and eventual priorities are configured.

2.3.4.3 Area Distribution Proposals

Specification: This type of proposal shall be designed to get an even distribution of observations on a sky region. The parameters are basically the number of visits per filter that are requested for each field in the region. It gives more ranking to the more needed field-filter combinations.

Discussion: A simplified version of the equations to rank the targets in order to achieve the distribution is as follows.

$$GlobalNeedFactor = 1 - \frac{GlobalVisits}{GlobalGoal}$$

$$FieldNeedFactor = 1 - \frac{FieldVisits}{FieldGoal}$$

$$FieldFilterNeedFactor = 1 - \frac{FieldFilterVisits}{FieldFilterGoal}$$

$$rank = IdleRank \frac{FieldNeedFactor + FieldFilterNeedFactor}{2GlobalNeedFactor}$$

If look ahead information is available and used, then the following self-balancing equations are used:

$$targetNeed = \frac{goalVisits - numVisits}{availableTime}$$

$$targetMerit = \frac{targetNeed}{\max(targetNeed)}$$

where

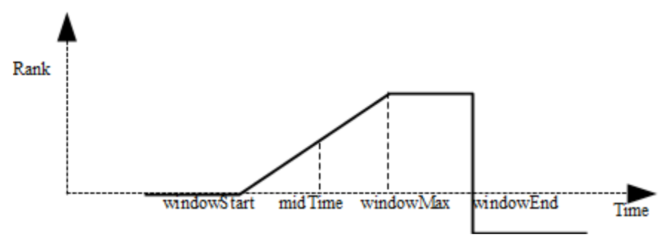
availableTime is the addition of the future time windows when the target (field-filter) is visible for the science program.

targetMerit gives a normalized range of values

Boost factor: There is an additional factor that, if activated, promotes the field-filters that are close to reach the goal number of visits to assure completion.

2.3.4.4 Time Distribution Proposals

Specification: This type of proposal is designed to work with transient targets, in which the fields need a sequence of observations at a given set of time intervals. Each field in the specified sky region has its own sequence independent from the others. An event in this context is an observation of the field that has to be performed during specific time limits given by the scheduling requirements of the sequence, and with a filter to be determined by the particular algorithm of the proposal.



2.3.5 Sequences in Time Distribution Proposals

The Scheduler shall implement the following variants on the behavior of the sequences for the time distribution proposals.

2.3.5.1 Basic Sequence

Specification: There shall be a sequence for each field in the defined region for the proposal. The sequence is defined by a filter, the number of visits to complete the sequence, a time interval between observations, and time window parameters for the tolerance.

2.3.5.2 Maximum number of missed observations

Specification: Each sequence is allowed to miss a defined number of visits. If there are more missed events than this threshold, the sequence is declared lost.

Discussion: The threshold for maximum allowed missed visits in a sequence is a configurable parameter, and can be different for the different subsequences in a proposal, and different for the different proposals.

2.3.5.3 Restart Sequence

Specification: There shall be a flag for restarting a complete sequence, and a flag for restarting a lost sequence.

2.3.5.4 Alternate area distribution with tuples collection

Specification: There shall be a type of sequence that collects visits in tuples. The first observation of the tuple shall obey an area distribution equation for its rank, and the subsequent observations of the tuple shall obey a time window equation for its rank.

2.3.5.5 Subsequences

Specification: There shall be a type of sequence that is composed of several subsequences for each field running in parallel. Each subsequence is defined by a number of events with a fixed time interval, a filter, its own time-window parameters and limit for missed events. They all run independently proposing field-filter combinations until all of them are complete or any of them is lost, declaring in either case the end of the whole sequence.

2.3.5.6 Deep drilling sequences

Specification: There shall be a special case of sequence that allows the schedule of back-to-back visits.

Discussion: A deep drilling sequence has a number of events defined, a time interval between the events, and the composition of the event. This composition is a series of back-to-back visits with filter changes potentially defined.

2.3.6 Sky Brightness model

Specification: The Scheduler shall contain a sky brightness model for dark time and twilight.

Discussion: The sky model provides the expected brightness level for every field in the present and evaluated future times for look-ahead capabilities.

2.3.7 Update of Sky Brightness model

Specification: The Scheduler shall be capable of receiving updates of the sky brightness model parameters, adapting it to new measurements and improvements in the accuracy of the model.

2.3.8 Cost function

Specification: The Scheduler shall include a configurable cost function to evaluate the possible targets offered by the active science proposals and select the best next target at any given moment.

Discussion: The main cost factor is the slew time and all the delays implied in repositioning the observatory from the last observation to the candidate target.

The initial formula for combining the slew cost with the value provided by the proposals is the following:

$$Rank = \sum Value + slewBonus * \frac{a}{(SlewTime + b)}$$

The parameter *slewBonus* controls the weight given to this cost over the value of the target, affecting the behavior of the Scheduler in much it avoids long slews sacrificing important farther away targets.

2.3.9 Filter Swap

Specification: The Scheduler shall include a configurable decision algorithm to select the filter to swap out at start of the new moon cycle when filter u is swapped in, and communicate that selection not later than the end of the previous night to the OCS main control application. Similarly, the swap back in operation is decided and notified by the Scheduler.

2.3.10 Self-balancing proposal progress

Specification: The Scheduler shall include the optional usage of self-balancing factors to promote the least advanced science proposals against the ones that have achieved higher progress.

$$programProgress = \frac{\sum numVisits}{\sum goalVisits}$$

$$programTime = \frac{elapsedTime}{totalTime}$$

$$programProgressIndex = \frac{programProgress}{\mathrm{programTime}}$$

$$programNeedIndex = \frac{1 - programProgress}{1 - \mathrm{programTime}}$$

$$programBoost = \frac{programNeedIndex}{programProgressIndex}$$

2.3.11 Deterministic look ahead

Specification:The Scheduler shall include deterministic look ahead information about the targets with respect to the particular science proposals, in order to incorporate that data into the potential look ahead algorithms.

Discussion: The look ahead information includes the following parameters for each target for a discrete vector of time slices on a defined look ahead time window.

- Alt-Az-PA coordinates
- airmass
- moon phase and distance
- sky brightness

2.3.12 Downtime handling

Specification:The Scheduler shall pause its operation when a downtime signal is received from the OCS, and resumes normal automatic operation as soon as the downtime is over.

Discussion: The downtime can be scheduled or unscheduled, of known or unknown duration. In any case, the known information is present in the downtime signal and the Scheduler will plan accordingly.

2.3.13 Warm start capability

ID: SCH-Int-4

Specification: The Scheduler shall include a warm start capability to support the restart of the code after an interruption, and resume the survey in a seamless fashion.

Discussion: One of the key secondary goals for this feature is to resume the survey with a modified set of science proposals that can take the previous history of observations and count the progress as if they were active in the past, allowing an efficient take over. The Scheduler reads the observations database from OCS-EFD at start and replays the proposals internally to count the hits on the past visits to rebuild the internal representation of the progress on each science proposal.

2.3.14 Dithering

ID: SCH-Int-6

Requirement: The Scheduler shall be able to implement dithering of visit pointings.

Discussion: The LSST visit pointings are defined with respect to a standard grid of sky coordinates. The survey will optionally execute the survey with visits pointing to locations displaced (dithered) from the nominal field centers. The algorithm for this dithering will be explored with post-processing of simulated data, and possibly will not be implemented in the Operations Simulator algorithm.

2.3.15 Operation in Event of Input Failure

ID: OCS-input-00

Specification: In the event of failure of any expected input, the Scheduler shall continue to operate with appropriate defaults.

Discussion: An expected input can fail due to lack of data, or due to data outside expected ranges. In either case, the operator will be notified, and the Scheduler will default to pre-defined values. For certain input failure conditions, automatic operation may be paused pending operator intervention.

2.4 Performance Requirements

2.4.1 Speed

Specification: The Scheduler shall process the available telemetry and the configured science programs to decide the next target in no longer than 20[ms].

Discussion: This is the maximum elapsed time between when all the inputs are updated and available in the Scheduler interface, and the next target is published by the Scheduler. Allocating an additional time of 10[ms] for Simulated Observatory Control System (SOCS) and communications, this time budget allows for the simulation of a full night (~1000 Visits) during a visit time (~30[sec]), and thus publication of an updated edition of the predicted pointing schedule at each visit.

2.5 Attributes

2.5.1 Multiple scheduling algorithms

ID: SCH-Int-3

Specification: The Scheduler shall support multiple scheduling algorithms that are consistent with the inputs, outputs, and functions described in this document.

Discussion: Very likely, different algorithms will be utilized for non-optimal conditions, such as low transparency or high sky brightness. Also, the main algorithm(s) will likely evolve during the survey.

2.5.2 Operations Simulator (OpSim)

ID: SCH-Int-1

Specification: The Scheduler shall accommodate scheduling algorithm modules developed and tested in the Opsim

Discussion: Algorithm development and testing on the OpSim will continue in parallel with the Scheduler development. Therefore the OpSim and Scheduler must be designed to enable transfer of algorithms from one to the other.

2.5.3 Implicit Scheduler requirements inherited from the Operations Simulator

ID: SCH-Int-2

Specification: Requirements for the OpSim are also based on the flow down of requirements described above. Since the Scheduler must utilize the OpSim scheduling algorithms, it shall also support the OpSim configuration parameters and inputs, differing in that the OpSim uses models or historical data, whereas the Scheduler has access to current actual data.

Discussion: The intention is that all OpSim scheduling functionality and optimization will be available in the Scheduler.

2.5.4 Global Survey Optimization

ID: SCH-REQ

Specification: The operations management structure shall provide a process for review of Scheduler performance and specification of Scheduler parameters (or equivalently metrics and metric weights) that will be utilized to balance science and technical performance with respect to multiple requirements.

Discussion: The requirements above refer to the optimization of individual survey performance measures that cannot always be maximized simultaneously. The adjudication of competing requirements is essentially a political process, and this will be provided specifically for the Scheduler.

3 Appendix A – Scheduler Use Cases

3.1 Normal Observing Operations

3.1.1 Universal Cadence

- **Primary actor**: acting observing manager
- **Preconditions**: facilities, environmental conditions and astronomical conditions are suitable for initiation of normal operations
- **Guarantees (postconditions)**: automated observing begins
- **Trigger**: initiation of observing, normally at evening twilight
- **Main success scenario**: automated observing continues without interruption

3.1.2 Deep Drilling

- **Primary actor**: acting observing manager
- **Preconditions**: facilities, environmental conditions and astronomical conditions are suitable for initiation of deep drilling proposal
- **Guarantees (postconditions)**: deep drilling observing on a field begins
- **Trigger**: auto-triggered by scheduler
- Main success scenario: deep drilling sequence for one field completes, and system returns to Use Case 1.0, normal observing

3.2 Recovery

3.2.1 Recovery from Lost Observation

- **Primary actor**: acting observing manager
- **Preconditions**: an observation has been lost
- **Guarantees (postconditions)**: observing history updated for any data loss; scheduler parameters reset as needed; automated observing continues
- **Trigger**: loss of data determined by internal system performance checks, or has failed 60-second DM quality control
- **Main success scenario**: automated observing continues with immediate repeat or non-repeat of observation determined by normal scheduler algorithms

3.2.2 Warm Restart

- **Primary actor**: acting observing manager
- **Preconditions**: normal observing has been paused

- **Guarantees (postconditions)**: observing history updated for any data loss; scheduler parameters reset as needed; automated observing continues
- **Trigger**: automated scheduler-driven observing interrupted
- **Main success scenario**: automated observing continues with continuation of interrupted sequences determined by regular scheduler algorithms.

3.3 Target of Opportunity (TOO)

3.3.1 Predefined TOO

- **Primary actor**: acting observing manager
- **Preconditions**: a TOO has been pre-approved, with an associated priority, and an observing script pre-defined, to be held pending an appropriate trigger
- **Guarantees (postconditions)**: current observing activity will be interrupted immediately or following completion of the current observation or sequence (depending on an urgency flag), telescope will slew to requested field, and the TOO sequence will execute
- **Trigger**: an alert trigger has been received, probably automatic, but possibly by observing manager interrupt
- **Main success scenario**: TOO sequence is initiated within requested time window, sequence is completed, and automated observing resumes with continuation of interrupted sequences determined by regular scheduler algorithms.

3.3.2 Unexpected TOO

- **Primary actor**: acting observing manager
- **Preconditions**: an unexpected TOO observation is requested with appropriate approval authority for targets and fields
- **Guarantees (postconditions)**: current observing activity will be interrupted immediately or following completion of the current observation or sequence (depending on an urgency flag), telescope will slew to requested field, and the TOO sequence will execute
- **Trigger**: human intervention
- **Main success scenario**: TOO sequence is initiated within requested time window, sequence is completed, and automated observing resumes with continuation of interrupted sequences determined by regular scheduler algorithms.

3.4 New or Revised Observing Program

It is likely that the Scheduler will be modified many times during the survey, including adjustment of algorithms and parameters and addition or deletion of observing proposals.

3.4.1 Modification of Scheduler

- **Primary actor**: operations scientist
- **Preconditions**: changes to the scheduler algorithms, parameters, or other components have been developed and approved for installation
- **Guarantees (postconditions)**: the modified Scheduler will begin operation with all history, status and other necessary information from the old Scheduler
- **Trigger**: project and science management decision
- **Main success scenario**: automated observing resumes with continuation of interrupted sequences determined by regular scheduler algorithms.

3.5 Backup Programs

3.5.1 Reduced Data Quality

- **Primary actor**: acting observing manager and scheduler scientist
- **Preconditions**: data quality is significantly reduced due to conditions, most likely reduced transparency or poor seeing, which are below the requirements of all regular observing scenarios
- **Guarantees (postconditions)**: the Scheduler will shift to an alternate program which has been foreseen for the conditions, or if none, will pause operations
- **Trigger**: observing manager decision
- **Main success scenario**: during low quality conditions, backup programs which can make use of the data are activated

3.5.2 All Fields Complete

- **Primary actor**: acting observing manager and scheduler scientist
- **Preconditions**: the requirements for one or more observing proposals have been completely fulfilled, and at some time there are no requests for observations from primary programs – secondary programs will have been predefined for this circumstance
- **Guarantees (postconditions)**: the Scheduler will continue observations without interruption for approved secondary program(s)
- **Trigger**: insufficient primary programs to fill observing queue
- **Main success scenario**: optimized use of on-sky time will continue after the completion of key project requirements

3.6 System Failure

3.6.1 Filter Not Available

- **Primary actor**: acting observing manager and scheduler scientist
- **Preconditions**: one or more filters is not available; the Scheduler design foresees this possibility
- **Guarantees (postconditions)**: the Scheduler will continue to carry out an optimized observing program based on the available filters
- **Trigger**: filter changer failure or withdrawal of filter from operation
- **Main success scenario**: standard scheduler algorithms continue to carry out correct optimization with reduced filter set

3.6.2 Image Quality Low

- **Primary actor**: acting observing manager and scheduler scientist
- **Preconditions**: data quality is significantly reduced due to technical failure, e.g. due to incorrect function of optics supports or active optics; the Scheduler design foresees this possibility
- **Guarantees (postconditions)**: the Scheduler will continue operations for several levels of degraded image quality, unless it exceeds an agreed limit
- **Trigger**: image quality reported by DM, and decision by acting observing manager
- **Main success scenario**: appropriate Scheduler performance is ensured, either automatically, or with human intervention

3.6.3 Detector Partial Failure

- **Primary actor**: acting observing manager and scheduler scientist
- **Preconditions**: part of the focal plane fails; the Scheduler design foresees this possibility
- **Guarantees (postconditions)**: the Scheduler will continue operations for partial failure
- **Trigger**: focal plane failure reported by DM or detector engineering
- **Main success scenario**: appropriate Scheduler performance is ensured, either automatically, or with human intervention

3.6.4 Reduced Operations Efficiency

- **Primary actor**: acting observing manager and scheduler scientist
- **Preconditions**: operations efficiency is reduced and expected to remain so for an extended period of time

- **Guarantees (postconditions)**: the Scheduler will continue to optimize operations for the current level of performance
- **Trigger**: OCS analysis of observation timing, and engineering analysis and report
- **Main success scenario**: Scheduler parameters describing telescope system parameters will be adjusted, and Scheduler algorithms will correctly optimize observing under the performance limitations

4 Appendix B – Higher Level Scheduler Requirements

4.1 Observatory System Specifications

4.1.1 Environmental Optimization

ID: OSS-REQ-0026

Specification: The survey scheduling shall be optimized against local environmental conditions to maximize the survey's scientific return. This optimization shall include the ability to adjust filters based on seeing conditions, the ability to avoid clouds with predefined opacity, and adjust to constraints derived from wind direction.

4.1.2 Multiple Science Programs

ID: OSS-REQ-0027

Specification: The survey scheduling shall be capable of optimizing scientific returns from multiple science priorities, numbering at least nSciProp.

Discussion: A science proposal will be defined by that include but are not limited to

- number of visits and distribution by filter;
- temporal of visit distribution and/or sequence definition;
- limits on astro-climate quality for observation;
- constraints on the location of visit fields;
- priority relative to other science proposals

Description	Value	Unit	Name
The minimum science proposal that the scheduling algorithm must be capable of optimizing over.	6	int	nSciProp

4.1.3 Parallax Factor Sampling

ID: OSS-REQ-0028

Specification: The scheduler shall enforce an even distribution of parallax factor over the sum of all visits in the 10- year survey.

4.1.4 Scheduling Assessment

ID: OSS-REQ-0029

Specification: The survey scheduling shall be adjustable based on periodic assessment of performance. This shall be done down to periods of 1 hour throughout the night and shall be based on actual accomplishments compared to objectives and current system technical performance.

4.1.5 Survey History Record

ID: OSS-REQ-0030

Specification: The LSST Scheduler shall maintain an independent record of all past observations and shall include Data Quality Assessment parameters determined by evaluation of the imaging data.

4.1.6 Temporal Visit Distribution

ID: OSS-REQ-0031

Specification: The scheduler shall be capable of enforcing 5 (TBR) defined temporal distributions of visits covering the fast sample area (defined in the SRD).

4.1.7 Visit Optimization

ID: OSS-REQ-0032

Specification: The survey schedule shall be optimized to maximize the number of scientifically useful visits per night.

4.1.8 Survey Planning and Performance Monitoring

ID: OSS-REQ-0033

Specification: The LSST shall provide the tools and administrative processes necessary to monitor the progress of the ongoing survey,provide reports on the progress of the survey, respond to feedback from the science community, and evaluate the impact of changing science priorities over the 10 year survey lifetime.

Discussion: It is expected that the performance of this task will require the use of detailed survey simulations in order to evaluate scheduling alternatives and optimize the future performance of the survey.

4.2 OCS Requirements for Scheduler

4.2.1 Schedule Survey

ID:OCS-REQ-0007

Specification: The OCS shall contain an automatic Scheduler, which organizes the outstanding observations in a way that optimizes observing time and achievement of the specified science goals.

Discussion: The science goals are described in terms of science programs. The OCS Scheduler includes these science programs as software components, with a high level of flexibility in order to be capable of implementing the particular cadence and distribution of each one of them. Scripting capabilities and adaptive parameters are also considered to cope with special purpose observations in the survey, and potential changes of the survey baseline definition.

4.2.2 Fully Automatic Scheduling

ID:OCS-REQ-0008

Specification: The OCS shall be capable of scheduling and operating the sequence of observations in a fully automated fashion during an entire night.

Discussion: The OCS obtains all the relevant information from the science programs priorities, history of observations, environmental conditions/forecasts and subsystems states in order to build the schedule and conduct the survey automatically.

4.2.3 Obtain Candidate Observations Automatically

ID:OCS-REQ-0009

Specification: The OCS Scheduler shall generate the list of candidate target observations for a visit in a fully automated fashion.

Discussion: The science programs running in the OCS Scheduler will provide each one with its own list of targets that are allowed to be observed and are also in need of visits. This group of lists is merged by the Scheduler to produce a single list of candidate targets for the next visit.

4.2.4 Rank Candidates

ID:OCS-REQ-0010

Specification: The OCS Scheduler shall evaluate the list of possible candidate targets with a numerical rank, based on the history of observations and goals of the active science programs, in order to consider the benefits of all the options in the scheduling algorithm.

Discussion: Each science program contributes with its own list of ranked targets according to the parameters for depth, filters, time interval distribution and specific cadence requirements. The Scheduler then takes these ranks into account when assembling the single ranked list of targets according to their scientific priority for the next visit.

4.2.5 Optimize Observing Time

ID:OCS-REQ-0011

Specification: The OCS Scheduler shall organize the sequence of observations optimizing the time spent collecting data.

Discussion: The natural way of achieving optimum observing time is by minimizing time spent slewing and changing filters. This objective will sometimes go in the opposite interest of the science goals for some science programs, and it is the job of the OCS Scheduler to make the best balance between the two for the time span of the survey.

4.2.6 Maximize Science Programs

ID:OCS-REQ-0012

Specification: The OCS Scheduler shall pursue the maximum goals achievement for each science program.

Discussion: The OCS Scheduler balances the attention given to each science program in order to obtain scientific profit of each visit, trying also to find targets that satisfy multiple science programs simultaneously.

4.2.7 Minimize Slew Time

ID:OCS-REQ-0013

Specification: The OCS Scheduler shall minimize the time spent in slewing and maximize the shutter open time.

Discussion: The OCS Scheduler considers the cost of observing the next visit. The cost is the time needed from the end of the current visit to reconfigure the observatory for starting the next visit. This is the time to be spent slewing the telescope, slewing the dome, changing the filter and preparing the camera for the exposures. The accumulation of these times during the night are to be minimized by improving the rank of targets with shorter slews.

4.2.8 Estimate Slew Delay for Candidate Observations

ID:OCS-REQ-0014

Specification: The OCS Scheduler shall estimate the slew delay time from the current state of the observatory to the position of each possible next target, in order to consider the cost of all the options in the scheduling algorithm.

Discussion: The slew delay is evaluated for each target in the aggregated list of candidates, and this time is considered along with the scientific rank in order to build the final ranked list of candidate targets for automatically choosing the next visit.

4.2.9 Dynamic Adaptation to Changing Conditions

ID:OCS-REQ-0015

Specification: The OCS Scheduler shall constantly adapt the sequence of observations in real time, according to the external environmental conditions and the particular requirements of sky quality of the outstanding observations in the active science programs.

Discussion: This short term adaptation must be in balance with the long term goals for the survey. Telemetry from the environment is key for this requirement. Weather conditions are accounted for in the ranking process of the targets.

4.2.10 Schedule Science Programs

ID:OCS-REQ-0016

Specification: The OCS Scheduler shall propose target observations according to the goals and parameters of the science programs described in the Observatory System Specifications.

Discussion: The OCS Scheduler shall select the best observation target sequence from the list of possible candidates, considering the benefit for the active science programs and the time cost of following that particular sequence.

4.2.11 Keep Track of Each Science Program Progress

ID:OCS-REQ-0017

Specification: The OCS Scheduler shall keep track of the detailed progress of each science program.

Discussion: In order to rank a particular sky field for the next visit, each science program needs to consider the number of visits granted for that field, the sequence of filters and the time distribution achieved so far, and evaluate those parameters for computing the science value for that particular field in the next visit opportunity.

4.2.12 Observations Database

ID:OCS-REQ-0018

Specification: The OCS shall keep a detailed observations database with the complete history of observations with their parameters and environmental conditions under which they were taken.

Discussion: This observations database is utilized for ranking the future visits and also for building automatic and on-demand reports about the survey progress, globally and for each science program.

4.2.13 Schedule Calibration and Maintenance Programs

ID:OCS-REQ-0019

Specification: The OCS shall schedule calibration and maintenance programs, according to the baseline plans. These programs shall allow automatic, scripted or manual observations according to the specific operational needs.

Discussion: During calibration and maintenance the OCS Scheduler works in a similar fashion, replacing the science programs by calibration or maintenance programs.

4.2.14 Update Survey Parameters

ID:OCS-REQ-0020

Specification: The OCS provides the interface to allow the updating of the Scheduler parameters following the analysis of the survey progress by the survey managers.

Discussion: The OCS Scheduler shall have a set of parameters that control the survey operation, such as active science programs, relative priorities, ranking factors, time limits, sky brightness ranges, etc. These parameters can be adjusted by the survey scientists and engineers after analyzing the survey progress reports.

4.2.15 Image Processing Control

ID:OCS-REQ-0021

Specification: The OCS shall inform the Data Management System in advance of the image acquisition of the needed processing related the specific image type.

Discussion: This requirement ensures that the Data Management operating at the Base Facility has advance notice of the type of image(s) that are being acquired. This is to inform the Data Management system of the type of processing it needs to perform on the images as they are obtained.