# Appendix D

# Observing Efficiency, Reliability and Availability of GSAO

## Introduction

This appendix to the preliminary design report for the Gemini South Adaptive Optics System explains the Observing Efficiency spreadsheet mcao_rely.xls, shown at the end of this document. The calculations cover the loss of observing time due to object setup overheads, satellite interference, interference with other observatories, clouds, and equipment failures. For a range of scenarios of varying optimism, 30 - 50% of the scheduled time on Cerro Pachon will be lost to these causes. The main conclusion is that observing efficiency is dominated by clouds, and by the relatively brief time chunks permitted for propagating lasers. These restrictions, intended to prevent harming satellites, provoke surprisingly frequent target acquisition overheads.

The spreadsheet also covers detailed failure calculations, including a sensitivity analysis of overall reliability (of the MCAO version of GSAO) as a function of laser system reliability. This analysis assumes that laser reliability is a free parameter.

## Top Level Requirements

The Functional and Performance Requirements Document for GSAO limits the maximum downtime due to failures to 10% of the scheduled time on the telescope. The FPRD also sets limits on various operational overheads, both day and night. Of particular interest, the target acquisition budget of 120 seconds and a daytime setup of 1 hour have the biggest impact on observing efficiency.

## Lost Time

This table shows the chief result that 30-50% of the night will be lost to various overheads.

| | | Total Down time | |
|---|---|---|---|
| | | Laser Format | |
| Satellite Interference Scenario | Satellite Loss | Pulse | CW (MCAO) |
| Full Setup + Astrometry | 12.9% | 30% | 38% |
| Partial Setup + Astrometry | 11.8% | 29% | 37% |
| Partial Setup, no Astrometry | 9.1% | 27% | 34.9% |
| Part Setup- no astr'y. - cal if laser off | 8.3% | 26% | 34.3% |
| Dwell on Same Object | 43% | 54% | 59% |

**Table 1 Lost time from Setup, Satellites, Other observatories, Clouds, and Failures**

The first row assumes we need a full two minutes to slew and acquire PWFS2, together with two more minutes for target acquisition including deploying science and AO fold mirrors, and averaging the Natural Guide star WFS tip/tilt readings prior to starting integration on the astronomical detector. The next row assumes that the AO fold and Science Fold mirrors are already deployed. The third row is for the case where astrometry is not necessary. The fourth row is for the commissioning case where we wait at the same target until the next permitted laser transmission time slot. These satellite interference scenarios are explained in more detail later, and calculated in the spreadsheet at the end of this appendix.

The first column gives credit to a pulsed laser for increased immunity to thin clouds, whereas nearly photometric conditions would probably be necessary for MCAO with multiple CW laser beams. Conventional LGS AO with a single laser beam would still be feasible with some loss in performance. The probability of clouds at Cerro Pachon is discussed in the section after next.

## Lost Time Calculation Method

To calculate the combined effect of the various losses, (satellite & observatory interference, cirrus, and failures) we treat the percentage of lost time for an item like cirrus as a probability of failure Pr(loss). Then the probability of success, or the chance that cirrus will not be a hindrance, is Pr(success) = 1 – Pr(loss)\

The product of these four success probabilities is the overall system useful percentage. One minus this percentage gives the lost observing time.

| **Example lost time calculation - no astrometry** | |
|---|---|
| Failures (from MTBF calculations below) | 10.0% |
| Cirrus Losses for Pulsed Laser | 8.9% |
| Losses from Satellite inteference (cal(no laser) short setu | 8.3% |
| Other observatory interference (min/night) | 2% |
| Total Lost Time (best case) | **26%** |

**Table 2 Sample Lost Time calculation - no astrometry**

The next several pages of the spreadsheet derive the estimates of the four loss categories.

## Object Setup Budget.

The budget for setting up on an object is broken into three phases:

- Slewing
- Target acquisition without laser beam
- Propagating the laser and closing the loop.

The Conceptual design review document suggested 120 seconds as a reasonable time to slew the telescope and acquire a star onto the Peripheral Wavefront Sensor #2. We use this figure for the worst case (where astrometry is also needed.)

Although a reasonable estimate of the time for target acquisition and closing the loop exceeds the FPRD requirement 0202c by 10%, this is however, the worst case. For the vast majority of the observations, the science fold and AO feed mirrors would already be deployed from the previous observation.

## Annual Scheduled Hours

The CoDR book says that half the nights per year (180), at ten hours per night, would be planned for MCAO observations. The efficiency is calculated as a fraction of these scheduled hours that is lost.

## Cirrus

For MCAO using multiple CW laser beams, the LGS WFS can tolerate virtually no backscatter from clouds. Otherwise, the background level on the WFS CCD rises too high, and may fluctuate on time scales of a few seconds, due to “fratricide” between the multiple guide stars. For a pulsed laser, where the possibility exists to range-gate the WFS, we have selected a threshold of 20% loss of light on the upward path, and a further 20% on the return. This corresponds to a one-way loss of 1/3 magnitude. With greater extinction, it is not worth operating MCAO.

We examined 3 years, (1997-1999) of sky cloudiness records at CTIO. The sky transparency was less than photometric, 46% of the time, with a year-to-year variation of ±4%. Thus, 46 per cent of the year would not be useable for MCAO with a CW laser system.

The time loss due to clouds with a pulsed laser is more difficult to determine from the CTIO rating system. CTIO assigns a score to each quarter night on a scale from 0 to 8 with 0 meaning cloudless and 8 totally overcast. On advice from photometrist Peter Stetson, we selected a score threshold of <3 to include an individual quarter-night in the total useful time for pulse laser guide stars. Using this relaxed criterion, sky opacity causes 30% loss of observing time for MCAO with a pulsed laser system, or conventional LGS AO with either a pulsed or CW laser.

In principle, since we are estimating the loss of "scheduled nights", if we had perfect weather forecasting to prepare the schedule, no observing time would be lost. A more realistic measure of MCAO availability is to consider what fraction of the astronomically useful nights are not suitable for MCAO, as shown in **Table 3**.

| | MCAO | | Useless |
|---|---|---|---|
| | CW | Pulse | Time |
| 1997 | 46% | 32% | 21% |
| 1998 | 49% | 31% | 19% |
| 1999 | 41% | 26% | 15% |
| **Average** | 46% | 30% | 18% |
| | Fraction of Useable Time Lost | | |
| **Classical** | 33.3% | 13.9% | |
| **Queued** | 18.9% | 8.9% | |

**Table 3 Lost time from clouds blinding laser beacon**

In this table, we start by calculating the percentage of annual night-time that is unsuitable for MCAO with CW and Pulse beacons. The last column is time lost to any form of astronomy, due to weather.

The second last row of the table presents the fraction of scientifically useable time (1-useless) that would be unsuitable for classically scheduled adaptive optics with laser beacons. This is the lost time fraction that enters into the overall calculations described above.

## Queue Scheduled Cirrus

Alternatively, one might imagine that instead of scheduling entire nights, we could start up the laser when it grew clear enough, to make use of partial nights in a queue-scheduling mode. It would take an hour to prepare the laser, before observing begins. We analysed the CTIO data in more detail as follows. For each quarter night, if it became clear enough, we would start the laser, and then get 1.5 hours observing. If the next quarter night was also clear, then we would get another 2.5 hours observing. The first quarter of the night was treated like the classical case in that the laser set-up was done during the daytime, so if the evening started clear, the first 2.5 hours was useable. It remains to be seen whether we can judge in the afternoon whether the night will begin with photometric conditions.

Fortunately, this scenario was much better for observing efficiency than the classical case of only starting the laser in the daytime. Some additional time gained by starting in the middle of the night was lost to setting up the laser after dark, as you see in the last row of **Table 3**.

As well, the annual operating hours on the laser was ~55% of the night hours in either case. For the classically scheduled mode, we plan to use half the 10-hour nights per year, and run the laser an additional 1 hour in the daytime, or 50%*11 / 10 = 55%. It is unclear whether more finely scheduled time may make a marginal improvement to the efficiency.

## *Satellite Interference*

A laser beacon should not interfere with satellites, neither to cause damage, nor to corrupt data from the satellite. Consequently there are time intervals when laser beacons are not permissible or advisable, in a given direction. The key statistics needed to analyze observing efficiency are the fraction of time the beam cannot be propagated, and the duration of a typical integration before the beam must be shut off.

Peter Wizinowich of Keck Observatory supplied copies of 24 faxed tables resulting from "Directed Energy Avoidance Requests" to the US military Space Command, the agency that catalogues orbits for satellites. Each request was to observe a particular star for a specific 3-4 hour period. Four were from the MMT site, and the rest from the Lick Observatory, which is a comparable distance from the equator (37 N) as Cerro Pachon (30 S). These tables show the time intervals that laser propagation is permitted and forbidden.

There is a tremendous variation in the duty cycle (fraction of time permitted) and the length of time allowed for a particular observation.

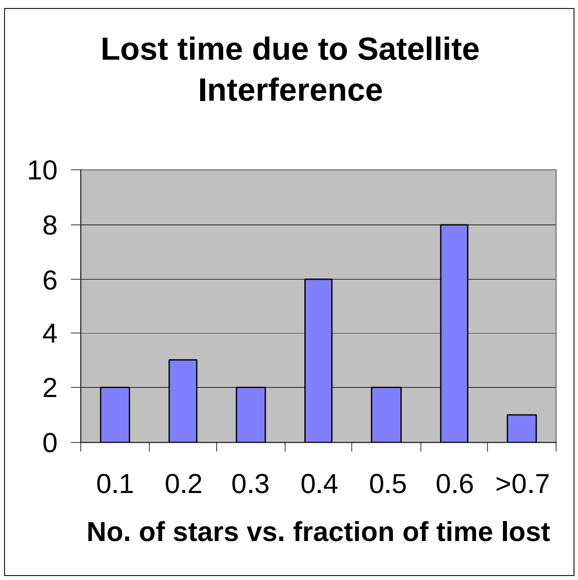


**Figure 1 Histogram of beam-off fractional time (24 stars)**

**Figure 1** shows that in the typical case, the beam must be off during ~40% of the planned 3-4 hour observing window. The median is 37.7% and the average is 38.5%. This average figure would affect efficiency only when considering the unlikely case of dwelling on the same object, and patiently waiting for the next time slot. More likely, a queue of observations will be prepared. The telescope would move to a new target, and pay the overhead of object-setup time.

## Length of dwell time

Thus, the duration of continuous propagation is the crucial factor. The longer we can launch a laser beam, the less often we have to move to a new target. Furthermore, many permitted time slots are so short that we do not have time to launch and acquire a laser and do astronomy.

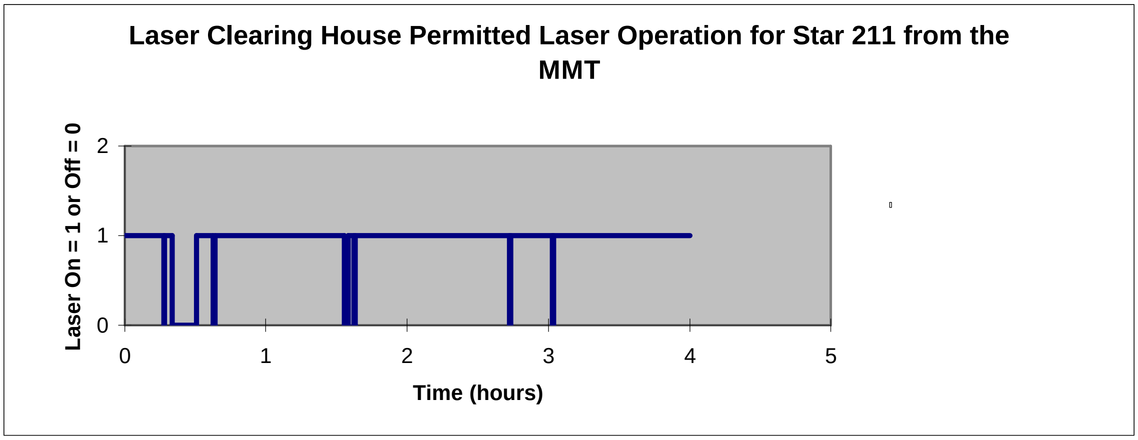


**Figure 2 Best Case**

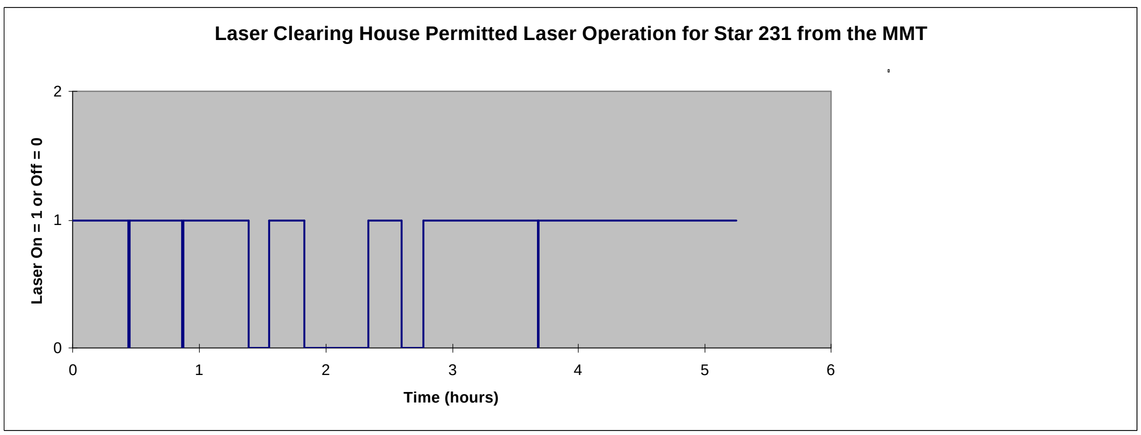


**Figure 3 Good Case**

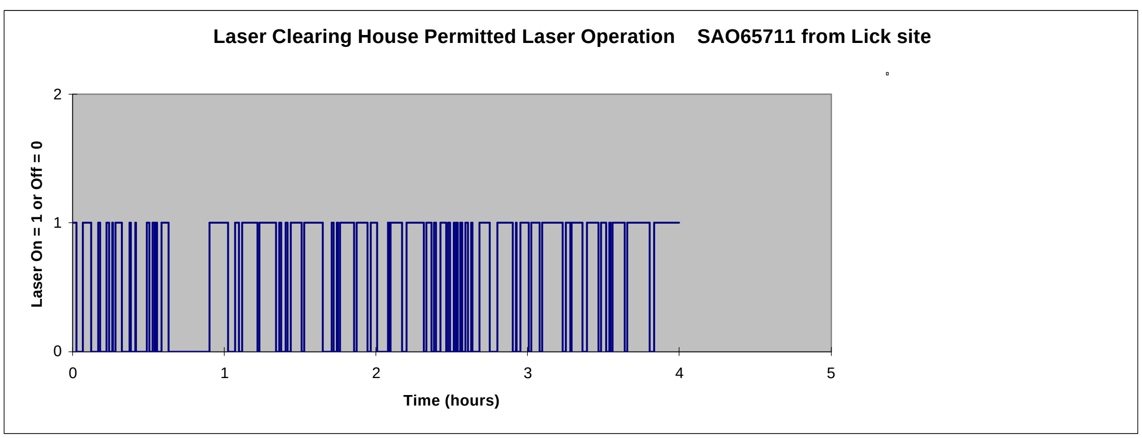


**Figure 4 Worst Case**

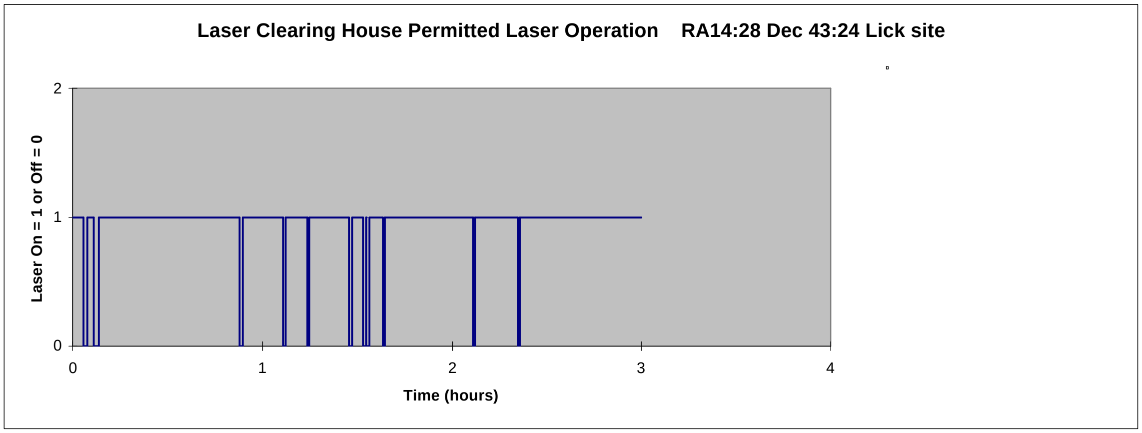


**Figure 5 Slightly better than typical Case**

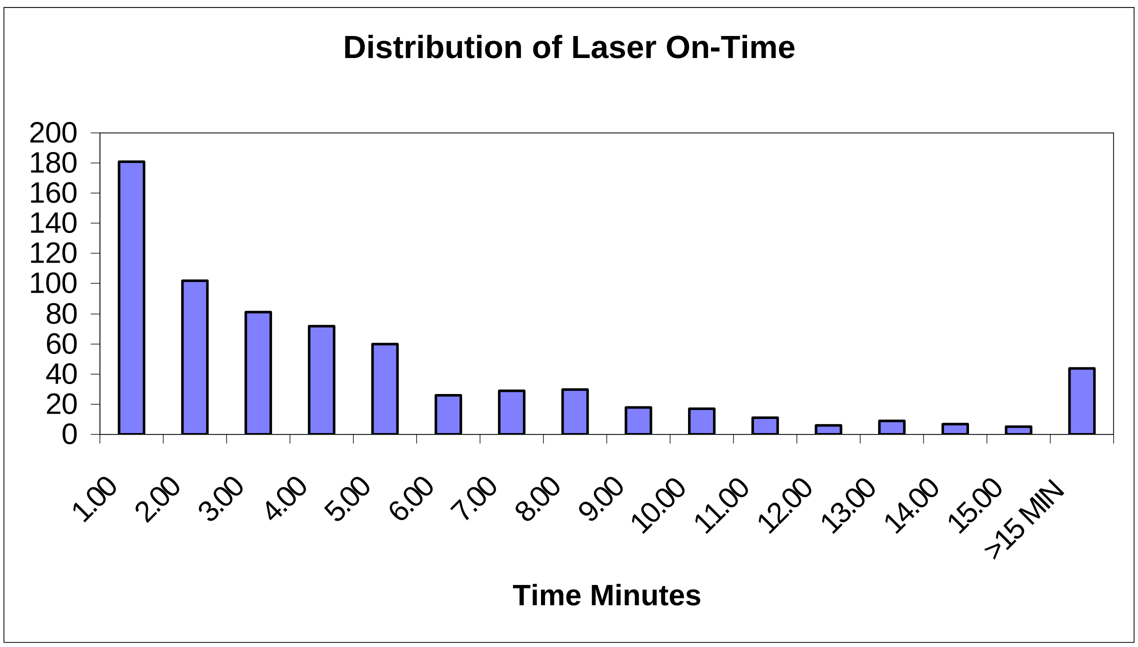


**Figure 6 Histogram of allowed propagation time**

**Figure 6** shows that the vast majority of the permitted time windows are far too short to do astronomy. Given the four minutes in the object setup time budget, we set a lower cut-off of 4 minutes propagation time before declaring a time slot useable. The results are shown for all 24 targets in **Table 4**, where the first data row shows the count of events when the beam was permitted more than four (or one) minutes. The total time, for all these events (in the next row), is divided by the number of events to give an average beam time used for the last satellite interference scenario below for dwelling and waiting on single object.

| **Average Useful Propagation Time** | **t>4 min** | **t>1 min** |
|---|---|---|
| Total Events > minimum (counts) | 262 | 508 |
| Total time > minimum (hours) | 47.7 | 59.4 |
| Average lasing time > min. (minutes) | 10.9 | 7.02 |

**Table 4 Average time laser is on**

Unfortunately, propagating the beam for an average of only 10.9 minutes means that we then must incur the overhead for object setup too frequently and take a loss of ~30% from satellite interference alone.

Instead we devised a better strategy. If we have a large enough queue, then when one observation finishes, we can pick a new target whose allowed beam propagation time is long enough to amortize the slew and setup overheads. How large a queue do we need?

A large part of the histogram **Figure 6** is well fit by an exponential probability function with a standard deviation (and thus a mean) of s = 5.1 minutes. However, there is a long tail of events t>15 minutes, better described by additional terms. Therefore, the probability of a single "laser on" event having a duration *t* longer than time T is given by the following equation (with s =4.8, b=2.99e-3, c=-1.8e-5).

$$\Pr(t > T) = e^{\left(\frac{-T}{s} + b \cdot T^2 + c \cdot T^3\right)}$$

Thus, there is only 1.8% chance that a time slot will be greater than or equal to 30 minutes. If we want to be assured that there is a reasonable chance of starting a long integration, we have to reduce our chance of failure by having N candidates to choose from whenever we start firing the laser.

$$\Pr(suc) = 1 - (1 - \Pr(t > T))^N$$

The probability of success rises as N increases. We can solve for N as a function of the uninterrupted time interval T, and the probability of successfully achieving it, Pr(*suc*).

$$N = \frac{\ln(1 - \Pr(suc))}{\ln(1 - \Pr(t > T))}$$

The following table shows the queue size N needed to be able to launch a laser for a desired integration time with a given probability. The left-hand column is the range of integration times considered. The second column is the probability that any single time slot will be at least as long as this integration time. The upper row of figures is the range of probabilities. Most of the satellite interference scenarios were evaluated by choosing 95% probability of getting 30 minutes of integration time, which requires a queue of 170 candidate targets to choose from each time the laser must be restarted. You can see that the queue grows rapidly for longer integrations

| Integ. Time | Probability P(t>T) | Desired Probability of Success 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 0.95 | 0.99 |
|---|---|---|---|---|---|---|---|---|
| 5 | 37.940% | 1.5 | 1.9 | 2.5 | 3.4 | 4.8 | 6.3 | 9.7 |
| 10 | 16.491% | 4 | 5 | 7 | 9 | 13 | 17 | 26 |
| 15 | 8.102% | 8 | 11 | 14 | 19 | 27 | 35 | 55 |
| 20 | 4.439% | 15 | 20 | 27 | 35 | 51 | 66 | 101 |
| 25 | 2.676% | 26 | 34 | 44 | 59 | 85 | 110 | 170 |
| 30 | 1.751% | 39 | 52 | 68 | 91 | 130 | 170 | 261 |
| 35 | 1.227% | 56 | 74 | 98 | 130 | 187 | 243 | 373 |
| 40 | 0.908% | 76 | 100 | 132 | 176 | 252 | 328 | 505 |
| 45 | 0.701% | 99 | 130 | 171 | 229 | 327 | 426 | 655 |
| 50 | 0.556% | 124 | 164 | 216 | 289 | 413 | 537 | 826 |
| 55 | 0.448% | 154 | 204 | 268 | 359 | 513 | 667 | 1026 |
| 60 | 0.361% | 192 | 253 | 333 | 445 | 637 | 828 | 1273 |

**Table 5 Queue size N vs. Integration Time and Probability**

## *Scenarios for Satellite Interference*

The four scenarios have a range of overheads, depending on whether astrometry is needed, and on whether the fold mirrors in the ISS are already deployed.

### 150 Target Queue with full Setup and Astrometry

We deduct, from the average laser propagation time of 30 minutes, the portion of the object setup time while the beam is launched, but astronomical integration cannot yet start. The net result is the available science integration time. At the end of integration, the beam must be shut down and the telescope slewed to a new target. Since the queue has few targets to choose from, then the typical slewing distance is large enough to incur the full slew and object setup overhead, before and after propagating the beam. The total cycle time is the sum of science integration, slew, and acquisition time for the next target, of which 13 % is unavailable to do astronomy. Note the 10 seconds penalty because there is a 5% chance that no target in the queue has a 30-minute time slot ready, and so we have to wait the 3.2 minutes average beam-off time for the next target.

### 150 Target Queue with partial setup and with astrometry

The AO and science fold mirrors remain deployed (i.e. the acquisition camera is not needed), so that the object setup time is reduced by 25 seconds. In this case only 12% of the cycle time is lost to astronomy.

### 150 Target Queue, with partial setup and no astrometry

Without astrometry, and with the fold mirrors continuously deployed, the acquisition time before propagating the laser beams is reduced further to cost 9% of the astronomically useful time.

### Wait on same target until propagation allowed again

This is the most inefficient scenario, but one likely to be used in early phases of science verification of MCAO. In this case, the average amount of beam time per night is divided by the cycle time to give the number of integrations per night. Here, the cycle time includes only the science integration and the beam-propagating phase of object setup, needed to restart after shutting down the beam. Since the beam dwells on the same object, we have made use of all time slots longer than 1 minute. The difference between the length of the night and the portion used for science is the lost time, or 43%. As you can see, the setup time to close the loop only slightly aggravates the 38.5% average downtime due to satellite interference.

Since this scenario is not expected beyond commissioning, we have not used it for the overall observing efficiency calculations.

## Preferred Method: Calibrate when laser off

Francois Rigaut suggested that a more realistic situation is to take several 15 minute integrations in different bands (e.g., J, H, and K). The probability of any single time slot being >15 minutes is ~8%. When the laser must be turned off, take calibration images such as sky flats. We estimate the MCAO-specific overheads in this spreadsheet section. Following PDR, we expect to do a more thorough simulation using the Gemini queue scheduling tools to see how likely this scenario is to find three 15-minute time slots, and not waste too much time for calibrations.

## *Interference with other observatories*

If a laser beacon crosses the field of view of a neighbouring telescope, the laser shall be shut down. From simulations, Doug Simons estimates this would occur about once per night. In such cases, on average, half of the 15-minute science-exposure time would be lost. This is an insignificant loss of observing, and is included only for completeness.

## *Mean Time Between Failure*

The overall failure rate and uptime of the MCAO instrument, beam transfer optics, launch telescope, and SALSA meet the requirements set in the FPRD and leaves a comfortable margin for the remaining item: the laser.

The percent of time lost due to equipment failure was calculated using the best available data for all components and subsystems except for the laser itself. The laser reliability was arbitrarily chosen to be 92 hours mean time between failures (MTBF) so that the resulting MCAO downtime met the 10% specification in the Functional and Performance Requirements. As well, we did a sensitivity analysis showing how variations in laser reliability affected MCAO as a whole.

The general calculation method for combining MTBF figures is analogous to adding resistors in parallel or springs in series. One takes the reciprocal of the sum of the reciprocals of the individual components' MTBF. Thus, the overall MTBF is dominated by the most unreliable subsystem. As well, in a system for example, with 5 critical components, each with the same MTBF, the resulting MTBF is 1/5 of the individual MTBFs. Consequently, the fewer critical components (whose failure causes lost time), the more reliable a system.

## AO Module

The above principle is illustrated in the section "Per LGS WFS". There are 5 key components, so the net MTBF for one WFS is 1/5 of the individual components' MTBF. And similarly, since there are 5 LGS WFSs, the MTBF is further reduced by 5 to produce an entry in the right hand column.

The AO module MTBF is largely driven by mechanisms of two types. Deployment mechanisms are simple dc motors that run until they reach a limit switch. Precision adjustment mechanisms use servo-motors and encoders with lower inherent reliability because they are more complex.

Xinetics estimates the reliability of deformable mirrors is predominantly set by the high power electronics. We derived MTBF for the Deformable mirrors by dividing the manufacturer's guarantee for Altair's DM by the ratio of actuators in MCAO. As well, the tip/tilt mirror MTBF is the guaranteed figure for Altair's mirror.

The combined MTBF for the AO module, as a whole, is estimated to be 528 hours.

## Beam transfer optics and Launch Telescope

The failure rate was estimated by counting mechanisms and adding in guesses for the diagnostics package, presumed to be somewhat less robust that say a CCD alone.

## SALSA

The satellite and aircraft protection system consists mostly of cameras, electronics and communications connections.

## Laser

The following sensitivity table shows the resulting system failure rate and loss of observing time due to failures of the laser system. Based on this sensitivity analysis, the rest of the observing efficiency was done assuming the laser has 48 hours MTBF, which allows meeting the FPRD specification of 10% lost time due to failures.

| **Laser MTBF** hours | **GSAO MTBF** hours | **Lost time %** |
|---:|---:|---:|
| 25 | 23 | 25.4% |
| 40 | 35.7 | 12.9% |
| 48.3 | 42.1 | 10.0% |
| 60 | 50.8 | 7.6% |
| 75 | 61.1 | 5.8% |
| 92 | 71.9 | 4.7% |
| 100 | 76.7 | 4.3% |
| 125 | 90.6 | 3.4% |
| 150 | 103.1 | 2.9% |
| 175 | 114.3 | 2.5% |
| 200 | 124.5 | 2.3% |
| 1000 | 247.9 | 1.0% |
| 2000 | 283.0 | 0.9% |
| 5000 | 309.3 | 0.8% |

**Table 6 Sensitivity of MCAO Reliability to Laser MTBF**

The laser would have to be twice as reliable to cut in half the lost time to failures, down to 5%.

## *Lost Time Due to Failures*

This section of the spreadsheet turns the MCAO mean time before failure of 42 hours into an estimated percentage of scheduled observing time lost due to those failures, to feed into the observing efficiency calculations. The expected number of failures in a time period is the operating time divided by the MTBF, or about 42 nighttime failures annually.

The working assumption is that once MCAO fails, up to one hour will be spent debugging, but then other observing will continue. The system will be fixed the next day.

However, the operating time-clock is also running during daytime preparation and engineering operations. The plan is to spend an hour every afternoon preparing the MCAO system. Unfortunately, if MCAO fails during these preparation operations, likely it is too late to repair it before sunset and the planned observing is lost. Such failures are expected to be only 10% as often as nighttime failures because 10x less preparation time is planned compared with nighttime observing.

Preventive maintenance during the daytime also runs the operating time-clock. The breakeven point for preventive and engineering maintenance is to spend as much time on it as you do on repairs. So we can expect another nine failures annually, caused by running the system during engineering time, each costing a planned night's observing.

Finally, we wish to emphasize that MCAO, exclusive of the laser itself, meets the requirements for uptime. In this analysis we have used laser MTBF as a free parameter to achieve the 10% lost time specification. If the laser is better than the minimum quality (~50 hrs MTBF), the MCAO observing efficiency can only improve.

# Observing Efficiency, Reliability, Uptime for GSAO System

G. Herriot NRC/HIA Apr 2001

## Top Level Requirements: FPRD

| | | | | |
|---|---|---|---|---|
| REQ-FPR-0608 | Downtime | | 10% | Max. fraction of scheduled time on telescope. |
| **Operational Overheads** | | | | |
| REQ-FPR-0202a | Daytime | 1 hour | | Max. Day time preparation operations |
| REQ-FPR-0202b | Nightly setup | 10 min | | Max Night time overall setup |
| REQ-FPR-0202c | Acquisition | 2 min | | Max Object setup(excluding telescope slew and |
| REQ-FPR-0202d | Dither | 3 s | | Max Dithering dead time between observations |

## Straw Man Budget for Object Setup

| | seconds | | |
|---|---|---|---|
| **Slew Telescope and acquire stars in PWFS2** | 120 | CoDR p116 | |

| **Target Acquisition and Closing the loop (OCDD sec 4.1)** | seconds/target | | |
|---|---|---|---|
| Deploy Science Fold and AO feed mirrors | 25 | | |
| Acquire OIWFS star and track via TTM & M2 | 10 | | |
| Deploy NGS WFS and acquire T/T stars | 10 | | |
| Close NGS alignment loops -- average for astrometry | 60 | **105** | No Beam |
| Align and propagate Laser beacons -verify quality | 10 | | |
| Verify constellation on LWFSs / Pupils on lenslets | 10 | | |
| Close BTO high bandwidth loops | 5 | | |
| Close TTM and DM loops | 3 | | |
| Acquisition Total | 133 | **28** | Beam<br>No science |

| | |
|---|---|
| Scheduled Nights per year | 180 |
| Hours scheduled per Night | 10 |
| Hours scheduled per year | 1800 |

## Lost time from Setup, Satellites, Other observatories, Clouds, and Failures

| | | Total Down time | |
|---|---|---|---|
| | | Laser Format | |
| **Satellite Interference Scenario** | **Satellite Loss** | **Pulse** | **CW** |
| Full Setup + Astrometry | 12.9% | 34% | 49% |
| Partial Setup + Astrometry | 11.8% | 33% | 48% |
| Partial Setup, no Astrometry | 9.1% | 31% | 46.5% |
| Part Setup- no astr'y. - cal when laser off | 8.3% | 30% | 46.0% |
| Dwell on Same Object | 43% | 56% | 66% |

| **Example lost time calculation - no astrometry** | |
|---|---|
| Failures (from MTBF calculations below) | 10.0% |
| Cirrus Losses for Pulsed Laser | 13.9% |
| Losses from Satellite inteference (cal(no laser) short setu | 8.3% |
| Other observatory interference (min/night) | 2% |
| Total Lost Time (best case) | **30%** |

Cirrus Losses for CW laser from CTIO photometric data 33.3%

## ***Details of Satellite Interference***

### Queue of 150 targets available + Full Setup + Astrometry Requ

| | | | | |
|---|---|---|---|---|
| 95% Probability Propagation Time- minutes | | 30 | 1800 | seconds |
| Deduct non-science beam propagation | | | -28 | |
| **Science Integration Time** | | | 1772 | Science In |
| Slew Time worst case including acquire PWFS2 star | | | 120 | |
| Acquistion Time, beam not propagating | 133 | -28 | 105 | |
| Acquisition time, Beam Propagating | | | 28 | |
| 5% Chance we have to wait * 3.2 minutes average time OFF | | | 10 | |
| **Total Cycle time** | | | 2035 | |
| Net interference | | | 12.9% | |

## ***Satellite Interference***

### Queue of 150 targets available + Partial Setup +Astrometry Re

| | | | |
|---|---|---|---|
| 95% Probability Propagation Time (min) -Space Commar | 30 | 1800 | seconds |
| Deduct non-science beam propagation | | -28 | |
| **Science Integration Time** | | 1772 | Science In |
| Slew Time worst case including acquire PWFS2 star | | 120 | |
| Acquistion Time, beam not propagating (mirrors already in ) | | 80 | |
| Acquisition time, Beam Propagating | | 28 | |
| 5% Chance we have to wait * 3.2 minutes average time beam OFF | | 10 | |
| **Total Cycle time** | | 2010 | |
| Net interference | | 11.8% | |

## ***Satellite Interference***

### Queue of 150 targets available + Partial Setup + No Astrometry

| | | |
|---|---|---|
| 95% Probability Propagation Time (min) | 30 | 1800 |
| Deduct non-science beam propagation | | -28 |
| **Science Integration Time** | | 1772 |
| Slew Time worst case including acquire PWFS2 star | | 120 |
| Acquistion Time, beam not propagating (mirrors already in ) | | 20 |
| 5% Chance we have to wait * 3.2 minutes average time beam OFF | | 9.6 |
| Acquisition time, Beam Propagating | | 28 |
| **Total Cycle time** | | 1950 |
| Net interference | | 9.1% |

## ***Satellite Interference***

### Wait on same target until propagation allowed again

| | | |
|---|---|---|
| fraction beam off ( from Space command) | 38.5% | |
| beam off, minutes per night | 13860 | |
| Acquisition time, Beam Pro | 28 | seconds |
| Average Science Integration Time | 393 | |
| Average Beam Propagation > 1 minιCycle time | 421 | |
| No of integration cycles per | 53 | |
| Science/ni | 20668 | |
| Net interference | 43% | |

## ***Preferred Method of Observing to avoid satellites***

Assume that all calibrations, sky flats, filter changes, are done during laser off-time.
Assume fold mirrors already in, no astrometry needed.

| | | | | |
|---|---|---|---|---|
| Slew Time worst case including acquire PWFS2 star | | | | 120 |
| Acquisition Time, beam not propagating | | | | 20 |
| Acquisition time, Beam Propagating | | | | 28 |
| *Integration J Band* | P(t>15)~8.1% | 15 min | | 900 |
| Acquisition time, Beam Propagating | | | | 28 |
| *Integration H Band* | | 15 min | | 900 |
| Acquisition time, Beam Propagating | | | | 28 |
| *Integration K Band* | | 15 min | | 900 |
| | | | Cycle Time | 2924 |
| | | | Science Time | 2700 |
| | | | Net Interference | 8.3% |

## **Details of Obervatory Interference**

| | | | | |
|---|---|---|---|---|
| Science integration time | minutes | 15 | | |
| Event occurs half-way through integration, so we lose, on average h | | | 450.0 | |
| Plus we have to wait for a new time slot (average time off) | | | 191.4 | |
| And we have to redo: Acquisition time, Beam Propagating | | | 28 | |
| | | | 669.40 | seconds |
| Number of incidents per night (D. Simons) | | 1 | | |
| | | Total Loss per night | 1.9% | |

## Mean Time Between Failure (MTBF) Calculations

| | | | | MTBF hours |
|---|---|---|---|---|
| **AO Module** | | | | |
| 35U of Conventional Electronics (SPE-S-G0046) | | | | 30000 |
| DM electronics | Xinetics 177 Actuators | | 5000 | |
| | Prorate for 4.2x as many channels | | | 1190 |
| Tip-Tilt Mirror | | | | 10000 |
| | | | | |
| Electromechanical Components | | | | |
| | Shutters | Input | | 100000 |
| | | Output | | 100000 |
| | Source Simulator | NGS | | 100000 |
| | | LGS | | 100000 |
| | Beamsplitter 1 | | | 100000 |
| | Science ADC | Prisms | | 25000 |
| | | Deploy | | 100000 |
| | LGS Zoom Collimat | Zoom 1 | | 50000 |
| | | Zoom 2 | | 50000 |
| | Per LGS WFS | | | |
| | | CCD | 50000 | |
| | | Lens1 | 50000 | |
| | | Lens2 | 50000 | |
| | | Lens 3 | 50000 | |
| | | Pupil Tip/Tilt | 50000 | |
| | | | 10000 | |
| | Quantity 5 LGS WFS | | | 2000 |
| | | | | |
| | NGS ADC | Prisms | | 25000 |
| | NGS WFS Stages | Qty 3, XY | | 8333 |
| | | | | |
| | Ref Source | XY | | 25000 |
| | | Deploy | | 100000 |
| | | | | |
| | Science HRWFS | XY | | 25000 |
| | | Deploy | | 100000 |
| | | Head | | 50000 |
| | | | | |
| | **Total for AO Module** | | | **528** |
| | | | | MTBF Hours |

| | | | |
|---|---|---|---|
| **Beam Transfer Optics** | | | 1107 |
| | Shutter | 100000 | |
| | Steering: Pier to top end | 8333 | |
| | Relay Optics L2, L3 | 25000 | |
| | M6, M7, slow steering | 12500 | |
| | M3 Slow Tip/tilt Arrray | 25000 | |
| | Diagnostics Case 1 | 20000 | |
| | M2 5x Fast Tip/tilt mirrors | 2000 | |
| | Flip/Fold/Beam Dump | 100000 | |
| | Rotator | 50000 | |
| | Electronics | 30000 | |

| | | | |
|---|---|---|---|
| **Laser Launch Telescope** | | | 25000 |
| | | | |
| **SALSA** | | | 5085 |
| | Narrow Field Camera | 20000 | |
| | Wide Field Camera | 20000 | |
| | Air traffic control radar feed | 50000 | |
| | Internet to CTIO & SOAR | 100000 | |
| | Electronics & Interface to BTO/Interlock | 15000 | |
| | | | |
| **Laser System** | | | 48 |

| | | |
|---|---|---|
| Gemini South AO MTBF | 42.1 | hours |
| Mean time between failures | | |

**Lost Time Due to Failures**

| | | |
|---|---|---|
| Scheduled Nights per year | | 180 |
| Hours scheduled per Night | | 10 |
| Hours scheduled per year | | 1800 |
| | | |
| Night Time Failures Per year | | 42.7 |

Assuming fault happens on average half-way through night, is debugged for 1 hour and is fixed the following day, then half integration + 1 hour is lost per incident.

| | | |
|---|---|---|
| Time for a single integration (min) | 15 | |
| Lost time to night failures hr/yr | | 48 |

**Daytime Preparation Operations**

| | | |
|---|---|---|
| time per scheduled night | | 1 |
| Hours scheduled per year | | 180 |
| Daytime Preparation failures annually | | 4.3 |
| | | |
| Repair time | 376.0 | |
| Engineering mainten. (breakeven ~= repair tim | | 376.0 |
| Annual failures during maintainance | | 8.9 |

Assuming daytime fault during preparation or maintenance prevents operation that ni

| | | |
|---|---|---|
| Lost observing time to daytime failures. | | 132 |
| | | |
| Total observing time lost to night + daytime failu | | 180 |
| **Percent of scheduled time lost to failures** | | 10.0% |