VLT(I) instrument operations and maintenance at the Paranal Observatory


Paranal Observatory, European Southern Observatory, Chile

ABSTRACT

The European Southern Observatory (ESO) operates its Very Large Telescope (VLT) on Cerro Paranal (Chile) with to date 11 scientific instruments including two interferometric instruments and their numerous auxiliary systems at 4 Unit Telescopes (UTs) and 3 Auxiliary Telescopes (ATs). The rigorous application of preventive and corrective maintenance procedures and a close monitoring of the instruments' engineering data streams are the key ingredient towards the minimization of the technical downtime of the instruments. The extensive use of standardized hardware and software components and their strict configuration control is considered crucial to efficiently manage the large number of systems with the limited human and technical resources available. A close collaboration between the instrument engineers, the instrument scientists in instrument operation teams (IOTs) turns out to be vital to maintain and to the performance of the instrumentation suite. In this paper, the necessary tools, workflows, and organizational structures to achieve these objectives are presented.

Keywords: ESO, VLT, observatory, instruments, maintenance, operations

1. INTRODUCTION

The Very Large Telescope (VLT) of the European Southern Observatory (ESO) started science operations on Cerro Paranal (Chile) seven years ago with two scientific instruments at one 8.2-m Unit Telescope (UT). Today, the Paranal Science Operations, Engineering, and Maintenance Departments support the operations of 11 scientific instruments and their numerous auxiliary systems at 4 UTs and 3 Auxiliary Telescopes (ATs). Two out of the 11 instruments are interferometric instruments coherently combining up to three UT or AT telescope beams (please refer to http://www.eso.org/paranal/insnews/ for detailed descriptions and latest information on the Paranal instruments and telescopes).

In this paper we present the instrument operations and maintenance work from the viewpoint of the Paranal Instrumentation Group [1]. The INS Group is part of the Paranal Engineering Department and takes up the responsibility for the individual instruments and guarantees their nightly availability for successful science operations. In the following we will review the role of the instrument operations teams, the achieved instrument performance in terms of availability and technical downtime, the performance monitoring tools, and the maintenance workflow.

2. VLT INSTRUMENT OPERATIONS

Successful instrument operations at the VLT is the result of a major effort across different ESO departments in Paranal (Chile) and Garching headquarters (Germany). The responsibilities for one specific instrument from the different departments form the so-call Instrument Operations Team (IOT). The IOT is composed of the

- Paranal Instrument Scientist(s) and Fellow(s) (Science Operations Department),
- Paranal Instrument Responsible Instrumentation and Software Engineers (Engineering Department),
- Garching User Support Scientist (User Support Department),
- Garching Quality Control Scientist (Data Flow Operations and Quality Control Group),
• Garching Pipeline Development Responsible (Pipeline Development Group),
• Garching Instrument Scientist (Instrumentation Division),
• Garching Instrument Responsible (Instrumentation Division),
and is chaired by the Paranal Instrument Scientist. After the operational instrument has been delivered to Paranal by Garching Instrumentation Division, operations is taken over by the respective operations groups, i.e., the Science Operations and Engineering Departments at Paranal and the operations groups of the Data Management Division in Garching, i.e., the User Support Department and the Data Flow Operations and Quality Control Group. Once the instrument is in operation and accepted by the observatory, the Instrumentation Division continues its support through technical and scientific advisory activities within the IOT and provides the necessary upgrades over the instrument’s lifetime. Reports on VLT Science Operations and Data Management can be found elsewhere in the different proceedings of this symposium.

At the Paranal observatory the core operations team consists of the Instrument Scientist and the Instrument Responsible Engineers from the Instrumentation and Software Groups. The Instrument Scientists focus their work on the scientific performance and the operational efficiency of their instruments. They define and implement the calibration plans, verify their execution and guarantee the quality of the data produced by the instruments. Data quality is their primary concern. The quality control process is supported by dedicated instrument data reduction and quality control pipelines as applied in real-time at the telescope during the science observations and calibration and off-line in Garching by the Quality Control group. High-level quality control (QC) parameters as measured by the pipelines are ingested to the regular engineering data stream and are available for the generation of automatic reports or offline analyses (cf. below). Examples for QC parameter trending as provided by the Garching QC group can be found at http://www.eso.org/observing/dfo/quality/.

Fig. 1. Report automatically generated by the AutRep system. In this example the daily measured pupil offset position in the MACAO adaptive optics system of the SINFONI instrument is shown over a report period of 60 days.
The Instrument Responsible Engineers on the other hand concentrate on the technical and system aspects of the instrument. They are responsible for the maintenance of the instrument and its performance and ensure the operational readiness of the instrument for the nighttime science operation and the daytime calibrations. A key ingredient for the performance maintenance of the instruments is the definition and execution of dedicated maintenance plans. This requires the availability of a detailed breakdown of the instruments in its maintainable subsystems and line-replaceable units (LRUs). The Instrument Responsible define the maintenance plans and provide the maintenance procedures and manuals based on the input received by the instrument builders and the experience from common subsystems with other instruments. The actual performance of the instrument and its subsystems is closely monitored through the engineering data stream as produced by any subsystem at the VLT. The engineering data stream uses the simple FITS keyword format (with the corresponding log files dubbed “FitsLogs”) and currently amounts for 150 Mb of data per day for the complete VLT(I).

The FitsLog data is available in an online database and is further ingested to the ESO science archive. The automatic report generator “AutRep” produces from these data sets predefined reports on a daily basis. Figure 1 shows one example of such a report using data as produced by the MACAO adaptive optics system of the SINFONI instrument. The automatic reports are inspected by the respective Instrumentation Engineers on a regular basis to detect possible trends in the subsystem and instrument performance or even unnoticed and hidden failures, which eventually might require the initiation of preventive or corrective maintenance jobs (cf. Sect. 4 below). AutRep further allows the interactive investigation of specific problems making use of the huge parameter space as provided by the engineering data of all VLT subsystems.

Table 1. The performances for all operational VLT instruments as measured by the shutter open efficiency (upper row) and the percentage of technical downtimes (lower row) over two observing periods in 2005 and 2006. For the definitions of the respective times, pls. cf. the text. All figures in percent.

<table>
<thead>
<tr>
<th></th>
<th>P75</th>
<th>P76</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Apr</td>
<td>May</td>
</tr>
<tr>
<td>ISAAC</td>
<td>57.3</td>
<td>70.3</td>
</tr>
<tr>
<td></td>
<td>1.6</td>
<td>9.4</td>
</tr>
<tr>
<td>FORS2</td>
<td>73.7</td>
<td>73.7</td>
</tr>
<tr>
<td></td>
<td>0.0</td>
<td>0.9</td>
</tr>
<tr>
<td>FORS1</td>
<td>56.3</td>
<td>72.7</td>
</tr>
<tr>
<td></td>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td>UVES</td>
<td>84.7</td>
<td>79.3</td>
</tr>
<tr>
<td>FLAMES</td>
<td>1.9</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>79.0</td>
<td>81.5</td>
</tr>
<tr>
<td></td>
<td>0.7</td>
<td>1.7</td>
</tr>
<tr>
<td>VIMOS</td>
<td>46.8</td>
<td>61.0</td>
</tr>
<tr>
<td></td>
<td>8.4</td>
<td>4.4</td>
</tr>
<tr>
<td>VISIR</td>
<td>56.1</td>
<td>68.5</td>
</tr>
<tr>
<td></td>
<td>1.1</td>
<td>0.0</td>
</tr>
<tr>
<td>NACO</td>
<td>41.8</td>
<td>51.8</td>
</tr>
<tr>
<td></td>
<td>8.8</td>
<td>0.8</td>
</tr>
<tr>
<td>SINFONI</td>
<td>72.0</td>
<td>68.6</td>
</tr>
<tr>
<td>MIDI</td>
<td>4.3</td>
<td>1.9</td>
</tr>
<tr>
<td>AMBER</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
3. VLT INSTRUMENT PERFORMANCE

For the communication of problems and actions among the different operations groups, ticket-based Problem Reporting Systems (PRS) play an important role. ESO adopted in 1996 the Remedy Action Request System, currently part of BMC Software Inc., as the standard to implement its PRSs. One implementation, the Paranal PRS (PPRS) is primarily used for problem reporting between the Science Operations and the Engineering Department but also within the Engineering Department. At the time of writing this article, 19500 PPRS tickets have been logged since the start of VLT operation in 1999 out of which 7600 tickets refer to the VLT(I) scientific instruments (and 3800 to the four Unit Telescopes). For any encountered problem that causes a loss of nighttime science operation time of a selected instrument, the corresponding “loss times” are recorded for the affected instrument. At the same time, the “shutter open time” of every instrument is recorded during its nighttime science operation as the true photon-collecting time on the instrument detector(s).

To measure the purely operational performance of the VLT instruments we define

- the technical downtime as the technical loss times relative to the available science time and
- the shutter open efficiency as the shutter open time relative to the available science time corrected for the technical loss times.

The available science time is measured as the nighttime between astronomical twilights and is corrected for time losses due to bad weather and operational losses, e.g. due to errors by the operators and the visiting astronomers and/or service mode users. The science time includes the observing time spent on calibration observations required to calibrate the instrument and the science data. Table 1 lists the technical down time and shutter open times for all operational VLT instruments over the observing periods 75 (April – Sept 2005) and 76 (October 2005 – March 2006). The average downtime of all instruments over this one-year period is 3% with shutter open efficiencies ranging from 8% for the MIR interferometric instrument MIDI to over 80% for optical spectrographs like UVES, FLAMES, and FORS. Shutter open efficiencies are subject to the very specific observing techniques of the individual instruments and measure primarily the unavoidable observational overheads of the instrument operation.

![Dissemination of Instrument Downtime](image)

Fig. 2. Breakdown of the technical loss times between the VLT instruments for the year 2005. For each individual instrument, the losses due to Software (SW) and Hardware (HW) problems are distinguished.

In the context of this paper, the technical downtime is of primary interest. The low average downtime of 3% as achieved for the VLT instruments is a key ingredient of successful and efficient science operation of the VLT. Figure 2 presents a breakdown of the technical loss times of the Paranal instruments over the year 2005 with a distinction for software and hardware problems. About 40% of the technical downtime (55% in number of the PPRS tickets) is attributed to software
problems despite the high level of standardization and configuration control of the VLT control software. The vast majority of the instrument control software from low-level devices to high-level templates is common to all instruments. However, the complexity of the remaining special devices and unavoidable individualities of the different instruments is sufficiently high to produce this significant number of problems and downtime. In many cases the complexity of the complete system does not allow to diagnose anymore the root cause of these software problems.

The distribution of hardware problems is rather even across the instruments but with a tendency of higher loss times for IR instruments. This is rather obviously due to cryogenic nature of these instruments involving high complexity and time consuming corrective actions. The optical VIMOS instrument sticks out from the downtime statistics and accounts alone for 40% of all instrument technical downtime in 2005. Over the last three years a major improvement and upgrade project has been undertaken by the Garching Instrumentation Division in collaboration with the Paranal Instrumentation Group to improve the reliability and performance of the VIMOS instrument while still operating the instrument in regular science operations. As a result of these efforts, the instrument has stabilized now at a 5% downtime (cf. Tab.1) level and is entering now the phase of intensive preventive maintenance to maintain and possibly further improve this performance.

It is interesting to note that in average, it takes 25 minutes at the VLT to solve an instrument problem during nighttime operation. This number is very similar for all instruments, but slightly higher for the IR versus the optical instruments.

4. VLT INSTRUMENT MAINTENANCE

In the paradigm of the VLT observatory operation, maintenance plays a key role. The rigorous execution of dedicated maintenance plans is considered crucial for having achieved the high availability and low downtimes of telescopes, instruments and their infrastructure as outlined above. In the following we will describe the maintenance principles as applied to the VLT instruments. Very similar workflows are in place for all VLT systems with the centralized coordination and support as provided by the Paranal Maintenance Department [2].

All VLT instruments and their subsystems are considered as repairable systems, i.e., systems that receive maintenance actions that restore and/or renew system components when they fail. To properly deal with such repairable systems, it is important to understand how components in these systems are restored (i.e., the maintenance actions that the components undergo). Instrument maintenance is defined as any action that maintains or restores the instrument performance at the nominal level, restores failed instrument units to an operational condition or retains non-failed units in an operational state. VLT instruments have a nominal lifetime of at least 10 years. Therefore, maintenance plays a vital role in their life. It affects the system's overall reliability, availability, downtime, and eventually the cost of their operation. The maintenance actions themselves are divided into three types: preventive maintenance, corrective maintenance and inspections.

**Inspections** are used in order to uncover hidden failures or degraded performance and are executed e.g. via periodic reports as they can be generated by the QC and AutRep system as describe before, or involve direct physical inspection of the hardware of the system. In general, no maintenance action is performed on the component during an inspection unless the component is found failed, in which case a corrective maintenance action is initiated.

**Corrective maintenance** consists of the actions taken to restore the instrument performance to its specification and/or restore a failed system to its operational status. This usually involves replacing or repairing the component that is responsible for the failure of the overall system. Corrective maintenance is performed at unpredictable intervals because a component's failure time is not known a priori. The objective of corrective maintenance is to restore the system to satisfactory operation within the shortest possible time. Therefore, the corresponding necessary interventions at the system do have an emergency character. The time limits for corrective maintenance actions for VLT instruments are in general set by the start of the next observing night or the start of an observing run of a visiting astronomer for which usually only one specific instrument is assigned. Flexible scheduling as available at the VLT for about 60% of the available science time in form of so-called Service Mode observations [3] plays an important role to relax these time limits and to allow successful science operation despite a temporary non-availability of an instrument, instrument mode or subsystem.
Figure 3 describes the workflow of corrective maintenance as implemented for the VLT instruments. The majority of the instrument problems requiring corrective maintenance is detected by the end-users of the instruments, i.e., by the operations staff (astronomers and telescope instrument operators) of the Science Operations Department. The problems are reported through PPRS tickets for evaluation by the group leader of the instrumentation group. For problems with known solutions the ticket is directly assigned to the maintenance team for the generation of the corresponding “Work Order” which triggers the execution of the required maintenance actions and supplies the executing party with the necessary information on the required resources in tools, spares, manpower and time, with the step-by-step maintenance procedures, and the relevant documentation to successfully complete the task. The execution of the task itself might require – depending on its complexity and demand on resources – the contributions of several groups within the Paranal Engineering and Maintenance Departments or in extreme cases the additional support from the Garching Instrumentation Division or external service providers. If on the other hand an unknown problem is encountered, the trouble shooting and solution definition is carried out within the instrumentation group under the responsibility of the respective Instrument (or subsystem) Responsible. After execution of the corrective maintenance tasks it is the responsibility of the Instrument Responsible to check and verify that the operational status and the performance of the instrument has been restored. In case of scientific instruments, the performance verification might require the support by the IOT or in particular of the respective Instrument Scientists. The reporting on executed and verified maintenance tasks back into the problem reporting system is particularly important for the newly encountered problems in case of their likely recurrence. The numerous PPRS tickets represent an invaluable database of problems and their solutions. If solutions have been identified, the corresponding maintenance tasks are defined and integrated in the respective maintenance plan.

Preventive maintenance, unlike corrective maintenance, is a schedule of planned maintenance actions aimed at the prevention of instrument breakdowns and failures in order to promote continuous system operation. The primary goal of preventive maintenance is to prevent the failure of the instrument or any of its subsystems before it actually occurs. It is designed to preserve and enhance instrument reliability and performance by replacing worn components before they actually fail. Preventive maintenance activities include equipment checks, partial or complete overhauls at specified periods. The schedule for preventive maintenance is based on observation of past system behavior, component wear-out mechanisms and knowledge of which components are vital to continued system operation. Deep knowledge and understanding of the instrument as a system and not only as the sum of its subsystems is crucial for successful definition of preventive maintenance plans. A close monitoring of suited system parameters from the engineering data stream (as e.g. described for the VLT above) paired with such a system understanding further allows to predict the time of failure of instrument components and trigger the corresponding maintenance actions before (predictive maintenance). E.g., Thorium-Argon hollow cathode lamps as widely used in optical high-resolution spectrographs display rapidly changing
line intensity ratios between ThI and ThII lines close to the end of their lifetime. Monitoring of such line ratios allows to replace the lamp before it fails during operation or even affects the quality of the wavelength calibration of the science spectra.

Preventive maintenance holds in particular long-term benefits, which should not be underestimated for large and costly facility instruments like the VLT instrument suite with expected life times of at least 10 years. Long-term benefits of preventive maintenance include: improved system reliability, decreased cost of replacement, decreased system downtime, and a better spares inventory management.

Figure 4 describes the preventive maintenance workflow of VLT instruments. All preventive maintenance tasks have predefined triggers from simple automatic periodic or fixed-date triggers to special external triggers by the Instrument Scientist and/or Instrument Responsible, the latter usually related to major overhauls. Once a preventive maintenance task is triggered, the workflow is very similar to the one of corrective maintenance tasks as described above and includes the same processing, execution and verification phases and respective responsibilities. However, the reporting and closing of the work order remains within the responsibility of the Maintenance Department.

All maintenance activities at Paranal are centrally managed by the Maintenance Department using the computerized maintenance management system (CMMS) Maximo by MRO Software. In addition to the already described work order generation for preventive and corrective maintenance plans, Maximo allows for:

- planning of preventive maintenance tasks,
- work flow monitoring and resource planning,
- failure reporting and tracking, and
- inventory control of spare parts and tools including their locations.
The successful implementation and execution of the described maintenance concepts requires that the concept of maintainability of an astronomical instrument is built-in right from the design phase. Consequently, ESO imposes strict requirements on their VLT instrument builders with respect to maintenance and availability, cf. [4]:

- corrective maintenance tasks restrict as much as possible to the exchange of Line Replacement Units (LRUs), with an LRU being a cryogenic, electronic/electrical, mechanical or optical instrument module or part that can be exchanged by a maximum of two technician level staff within a period of 4 working hours. The individual LRUs must be small enough to be easily transported for repair. Replacement LRUs are, as far as possible, completely interchangeable with the originals and do not require extensive alignment or calibration procedures,

- sufficient spare LRUs and other spare parts need to be delivered with each instrument corresponding to the likelihood of breakdown, the importance of the component to the functioning of the instrument, the time needed for repair (including the delivery time of critical parts), and the specified lifetime of the instrument,

- strict use of standardized components, which allows to simplify and accelerate the design process for VLT instruments, assures the mutual compatibility between all VLT sub-systems, reduces the required stock of spare parts on Paranal, maximizes the commonality between all installed VLT equipment and instruments to allow the observatory staff to become familiar with new systems in the shortest possible time, simplify the maintenance activities and to reduce the global cost of operations at the observatory. The requirement for standardization includes the instrument control and data reduction software.

5. CONCLUSIONS

In this contribution we have presented the operational principles and performances of the VLT instrument suite from the point of view of the Instrumentation Group within the Paranal Engineering Department.

The complexity of modern astronomical instrumentation and the VLT end-to-end operation model require a multidisciplinary team of engineers and scientists to successfully operate such facilities. The ESO Instrument Operation Teams and in particular at the front-end of the observatory, the Instrument Scientists and Instrument Responsible Engineers carry out these tasks with great success: technical downtimes of instruments are with an average of 3% very low while consistently high shutter open efficiencies are achieved indicating low operational overheads for the majority of the instruments. We conclude that the reported low downtimes are the direct result of the rigorous definition and application of dedicated instrument maintenance plans for preventive and predictive but also corrective maintenance tasks. The maintainability of instruments requires modular instrument designs based on Line Replacement Units and highly standardized hard- and software components. Corresponding design requirements are formulated in ESO’s requirement documents for VLT scientific instruments.

With the currently ongoing integration and commissioning of CRIRES, the first generation of VLT instruments will be completed soon and Paranal Observatory will enter its phase of full-scale instrument operations. At the same time, the second generation of VLT instruments with HAWK-I, X-Shooter, KMOS, and MUSE is already on the horizon. The increased complexity in particular of the latter two new instruments will for sure pose new challenges not only on the instrument designers and builders but also on the future operations and maintenance teams at Paranal Observatory.

REFERENCES

3. F. Comeron, G.Mathys, A.Kaufer, O.Hainaut, P.Quinn, VLT Service Mode operations at 7 years, Proceedings of the SPIE, this volume